Dec. 8, 2005
@FNAL PAC

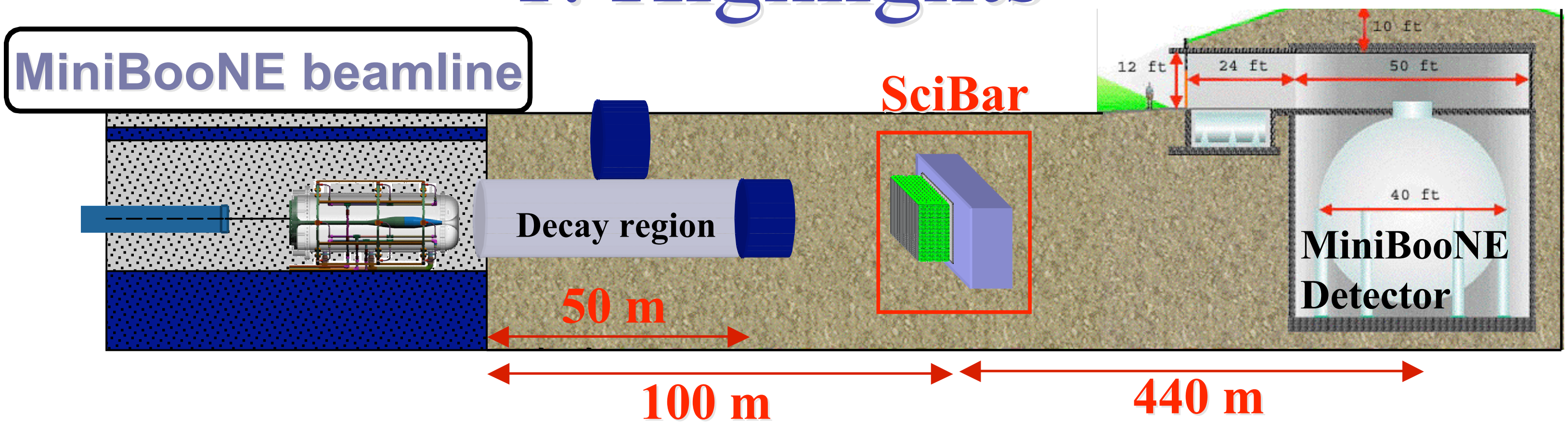
SciBooNE (P-954) Proposal

K2K ***Sci***Bar detector at FNAL ***Boo***ster ***N***eutrino ***E***xperiment

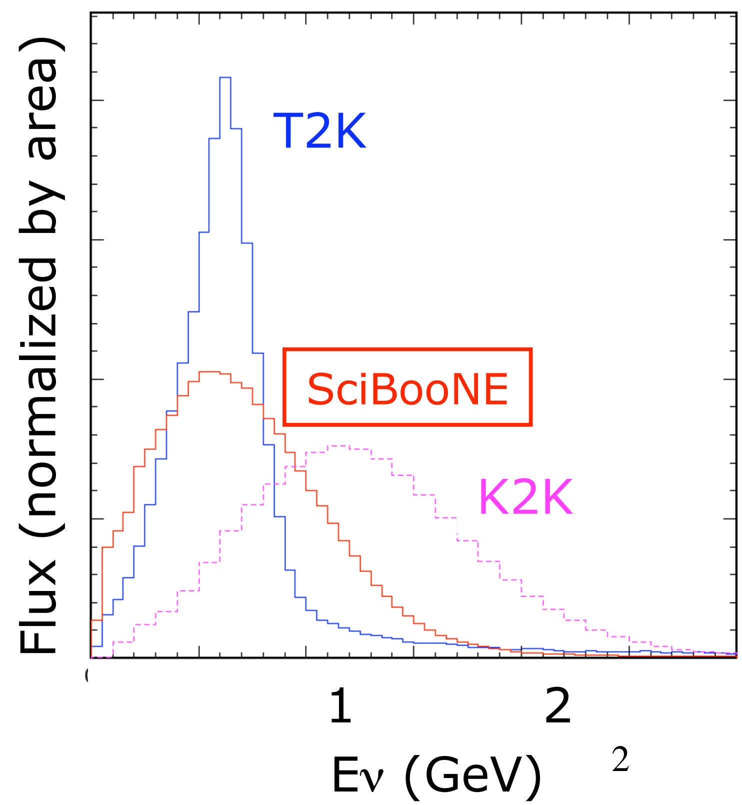
T. Nakaya (Kyoto) and M. Wascko (LSU)

for the SciBooNE Collaboration

1. Highlights



- Combine well developed detector with well understood running beam
  - Short timescales and modest cost
- Precise knowledge of σs necessary for T2K and other experiments
  - Non quasi-elastic ν interactions
- MiniBooNE near detector.
  - Confirmation, redundancy for BNB νs
- Antineutrinos
  - Currently unexplored physics territory.



Collaboration Members

- Barcelona — F. Sanchez, J. Alcaraz, S. Andringa, X. Espinal, G. Jover, T. Lux, F. Nova, A. Y. Rodriguez
- Colorado — M. Wilking, E.D. Zimmerman
- Columbia — J. Conrad, M. Shaevitz, K. B. M. Mahn, G. P. Zeller
- FNAL — S. J. Brice, B.C. Brown, D. Finley, T. Kobilarcik, R. Stefanski
- KEK — T. Ishii
- Kyoto — T. Nakaya, M. Yokoyama, H. Tanaka, K. Hiraide, Y. Kurimoto, K. Matsuoka, M. Taguchi, Y. Kurosawa
- LANL — W.C. Louis, R. Van de Water
- LSU — W. Metcalf, M. O. Wascko
- Rome — L. Ludovici, U. Dore, P. F. Loverre, C. Mariani
- Stratton Mtn — L.Bugel
- Valencia — J. J. Gomez-Cadenas, A. Cervera, M. Sorel, A. Tornero, J. Catala, P. Novella, E. Couce, J. Martin-Albo

11 institutes, 45 people

(*) Potential Ph.D. thesis students, Institute representative

Outline of this presentation

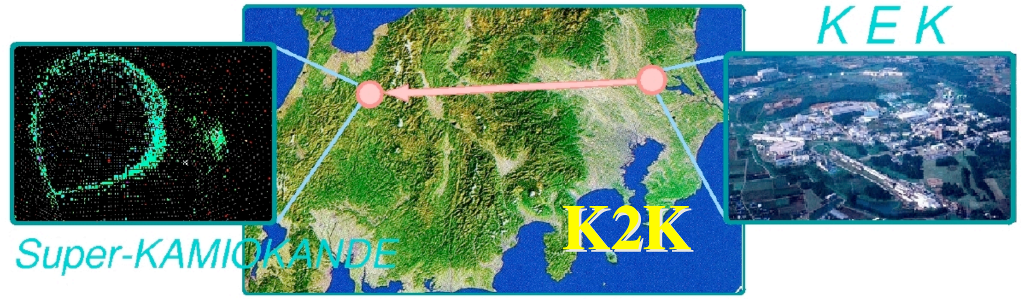
1. Highlights
2. Introduction
    1. Neutrino Physics
    2. Neutrino Cross Sections
3. SciBooNE Overview
    1. Physics Motivation
    2. FNAL Booster Neutrinos
    3. SciBar Detector
4. SciBooNE Physics
    1. Overview
    2. Neutrino Run
    3. Antineutrino Run
5. Logistics
6. Conclusion

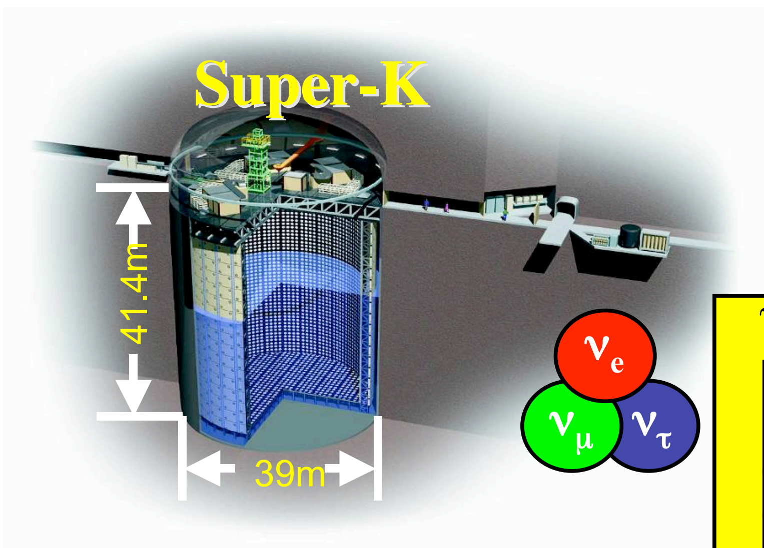
Nakaya

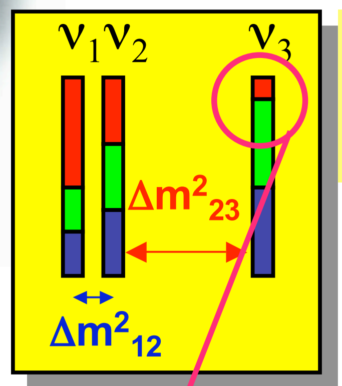
Wascko

2. Introduction

- Neutrino Oscillations (1998-2005)

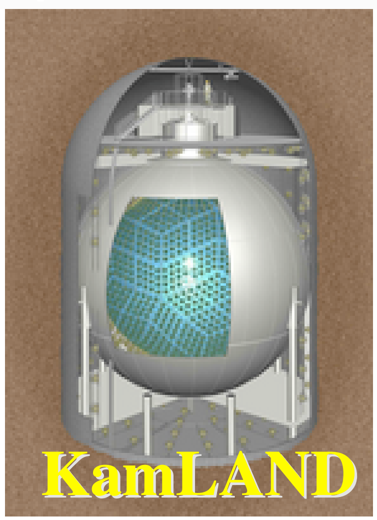


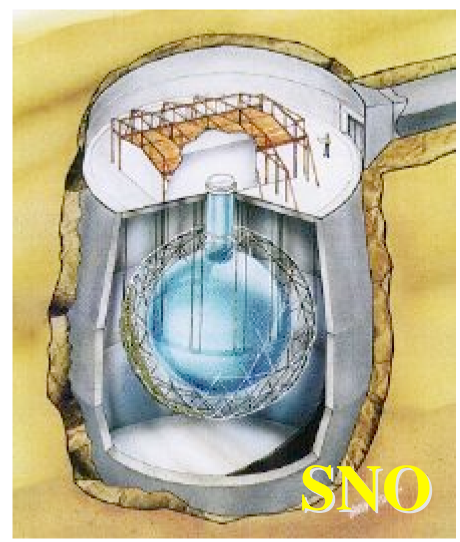


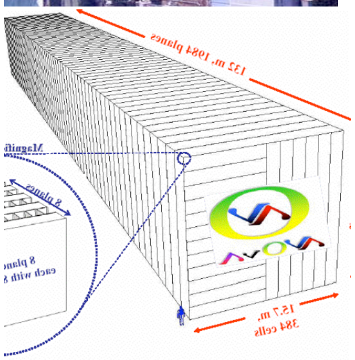


Neutrino masses **(Δm_{12}^2, Δm_{23}^2)**
Mixing Angles **(θ_{12}, θ_{23})**

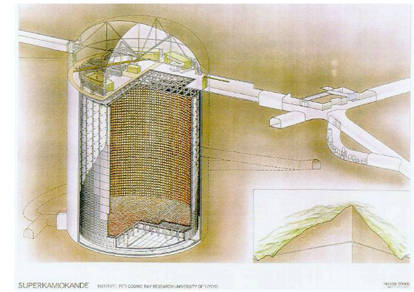
$\theta_{13} \rightarrow \delta$







Next Step (2006-2015)



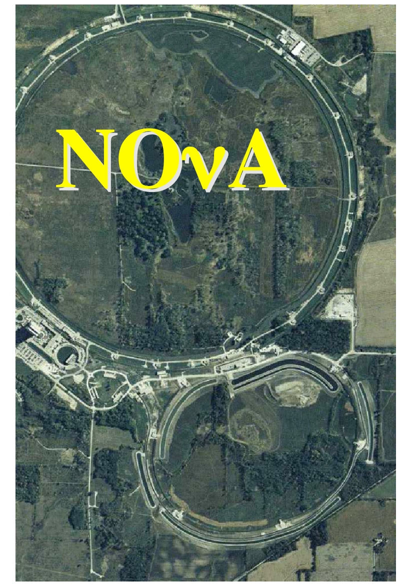
ν_e ν_μ ν_τ

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \mathrm{U}_{\mathrm{MNS}}\mathrm{V}_{\mathrm{M}}^{\mathrm{CP}}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij}$$

$$s_{ij} = \sin\theta_{ij}$$

ν_1 ν_2 ν_3

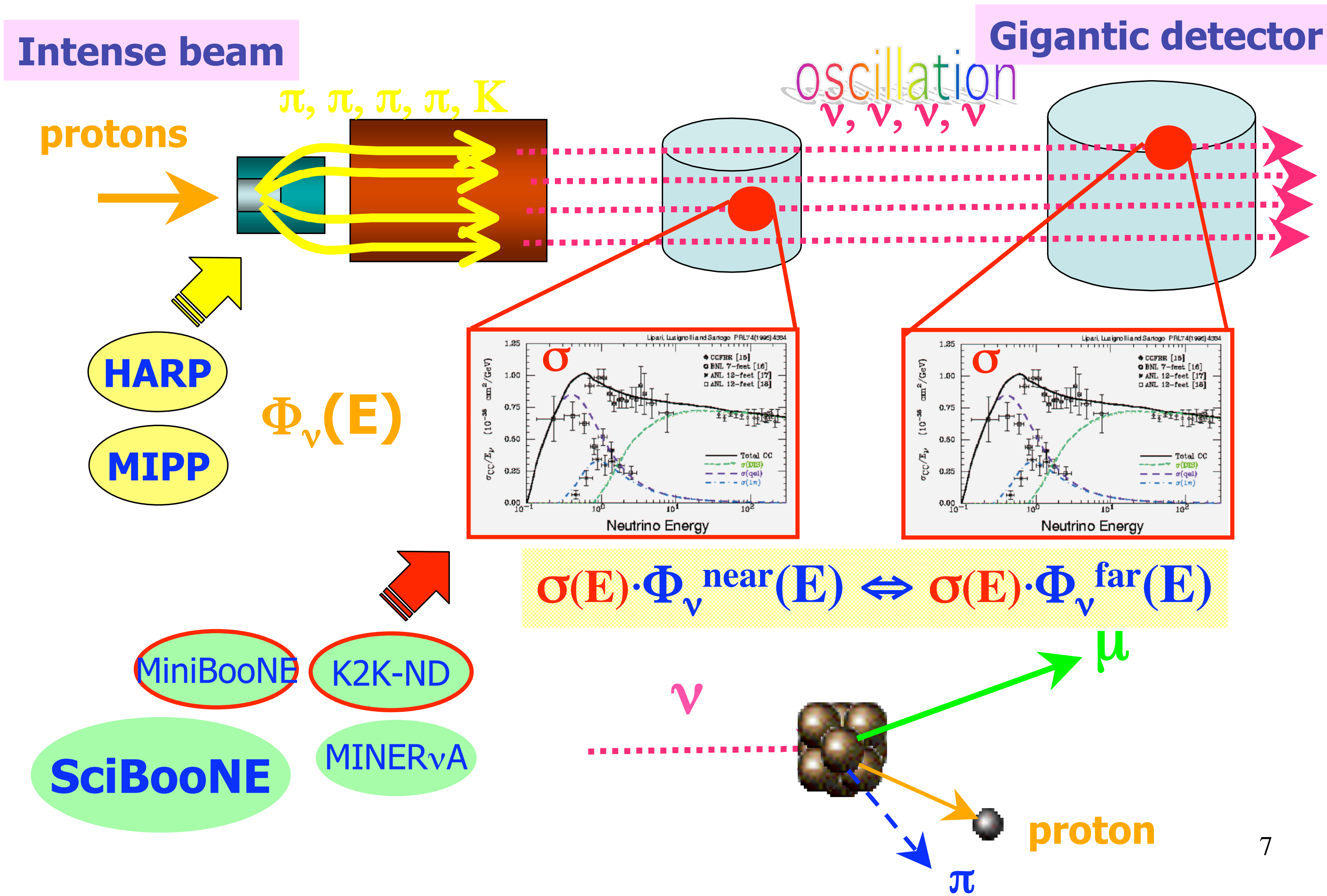


$$U_{MNS} = \boxed{\begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}} \times \boxed{\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{-i\delta} & 0 & c_{13}\end{pmatrix}} \times \boxed{\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}}$$

atmospheric **Cross Mixing** solar

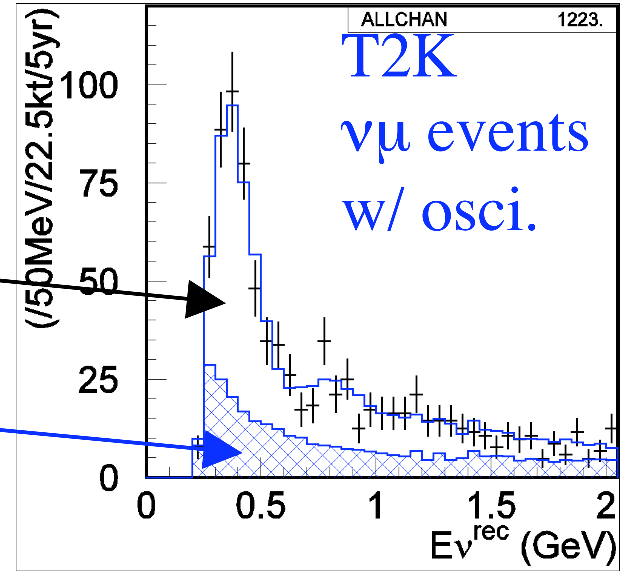
- Discover the last oscillation channel
  - θ_{13}
- CP violation in the lepton sector $(\nu,\bar{\nu})$
  - δ
- Mass hierarchy
  - **The sign of Δm_{23}^2**
- Test of the standard ν oscillation scenario (U_{MNS})
  - Precise measurements of ν oscillations ($\pm\Delta m_{23}^2$, θ_{23})

Strategy of accelerator ν oscillation experiments.



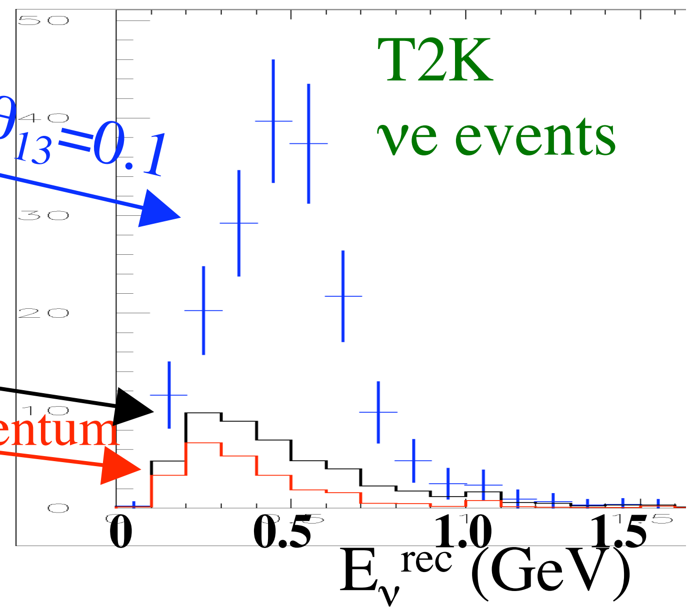
Impact of Neutrino Cross sections on oscillation measurements

- $\nu_\mu \rightarrow \nu_\mu$: precision measurements (θ_{23} and Δm_{23}^2)
  - Signal: CC-QE (ν+n$\rightarrow\mu$+p)
    - Energy Reconstruction from μ kinematics
  - Background: Mainly CC-1$\pi^\pm$ (ν+N$\rightarrow\mu+\pi$+N')
    - Cross section with **the visibility of π**



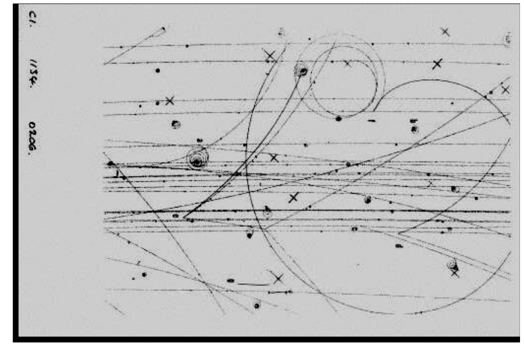
- $\nu_\mu \rightarrow \nu_e$: search for θ_{13}
  - Signal: CC-QE (ν+n$\rightarrow$e+p)
  - Background
    - Beam ν_e
    - NCπ^0
      - Cross section as a function of the momentum

$\sin^2 2\theta_{13}$=0.1

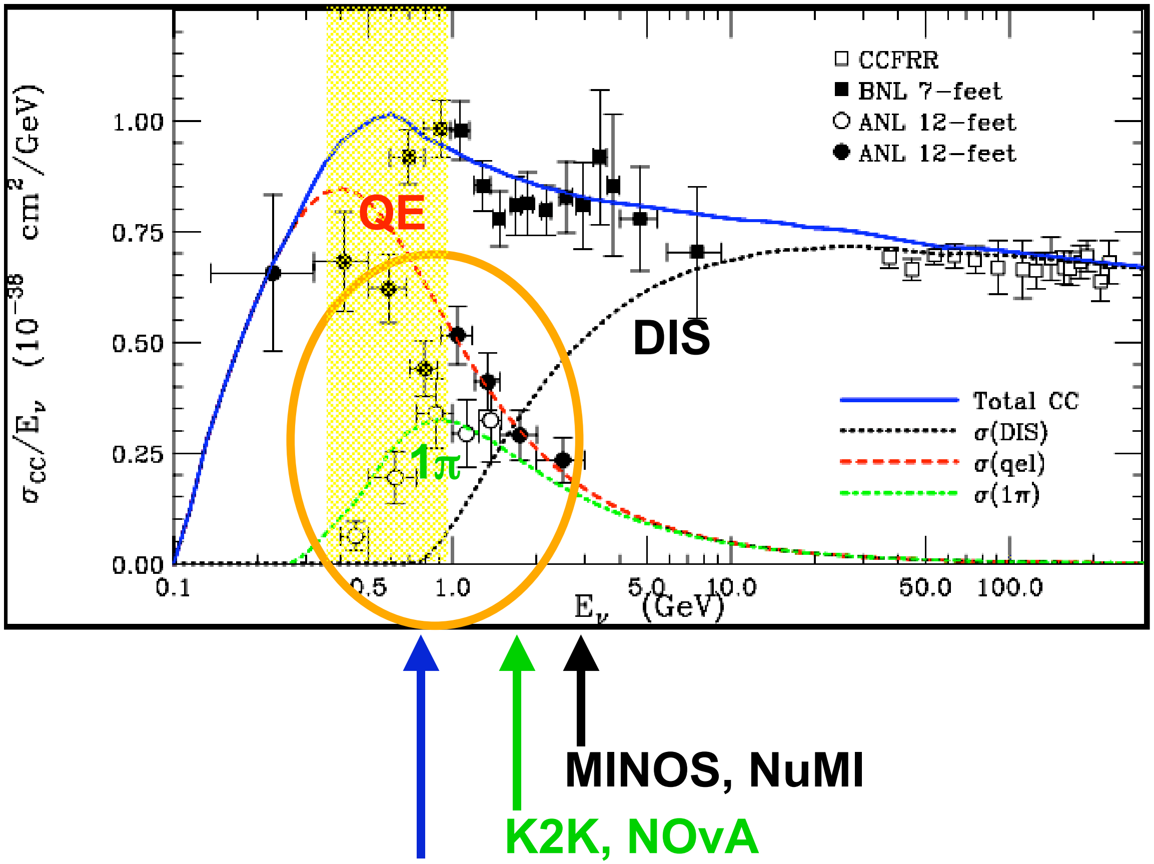


Anti-ν for CP violation study

Unexplored Areas of Neutrino Physics



σ_ν in this E range of interest:



MINOS, NuMI

K2K, NOvA

MiniBooNE, T2K, SciBooNE

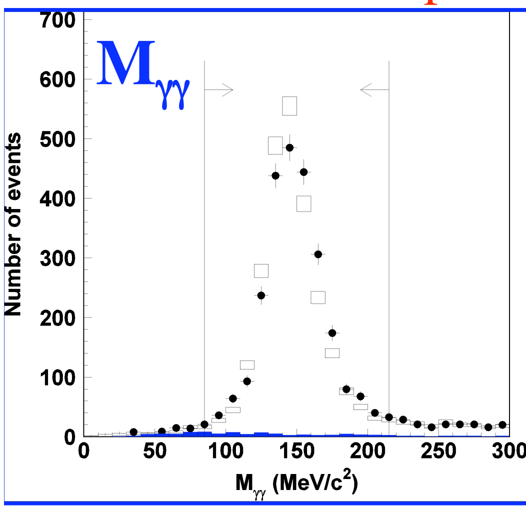
Super-K atmospheric ν

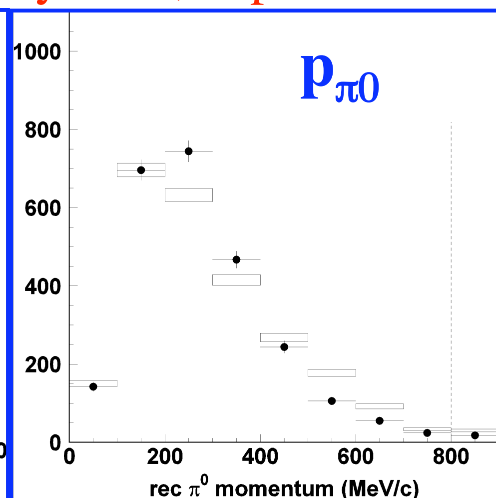
- **Data from old experiments** (1970~1980)
  - Low statistics
  - Systematic Uncertainties
- **Nuclear effects** (π/p/n absorption/scattering, shadowing, low Q^2 region)
  - Not well-modeled
- **New data** from MiniBooNE & K2K revealing surprises
- **More data at 1GeV with fine grained resolution will advance Neutrino Physics.**

Anti-ν cross section is in a poor situation.

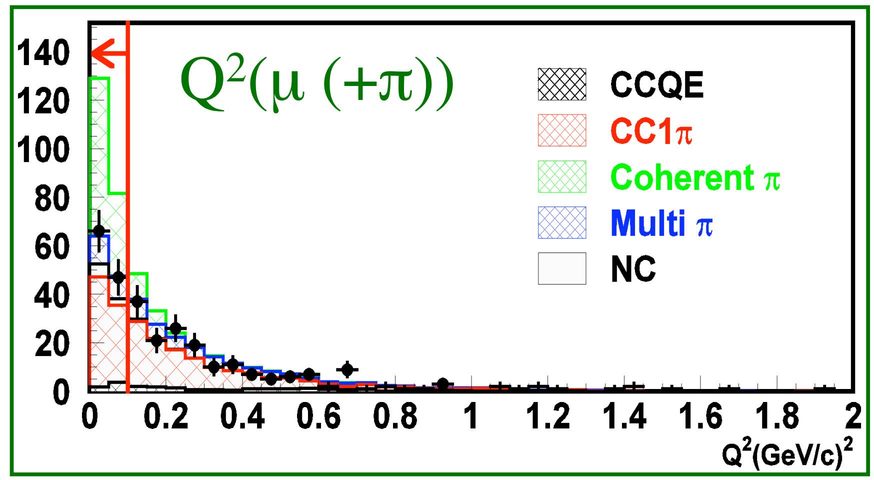
K2K results on the neutrino cross sections.

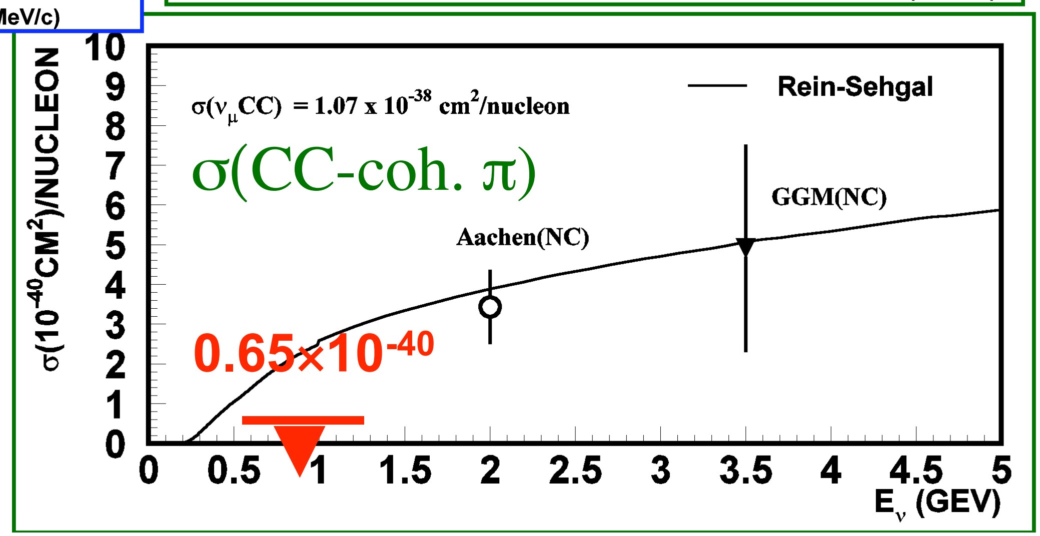
- Measurement of NC-1π^0 cross section (1KT).
  - PL B619(2005)255-263
- Limit on CC-coherent π cross section (SciBar).
  - Accepted by PRL, hep-ex/0506008





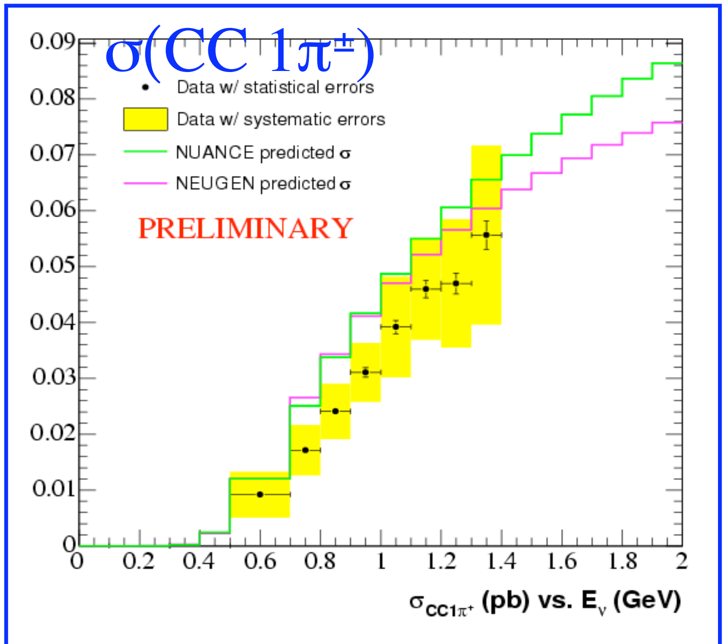
$\sigma_{NC1\pi 0}/\sigma_{CC\text{-all}}$
=0.064±0.001 ±0.007 (MC: 0.065)

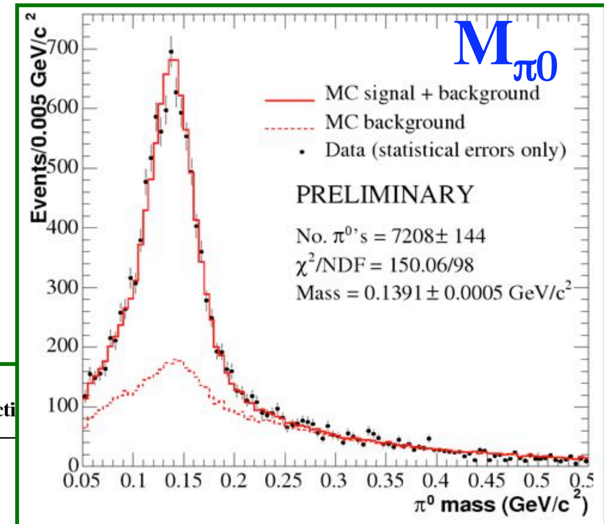


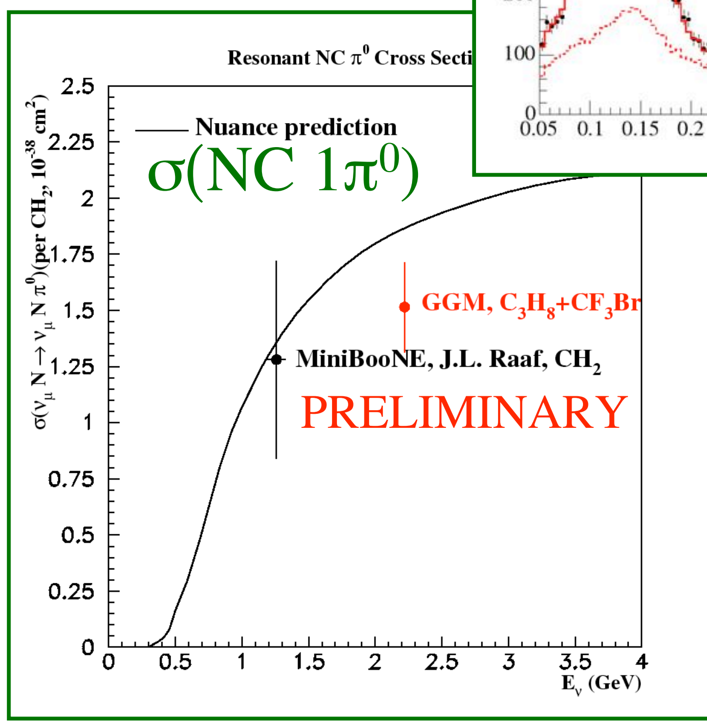


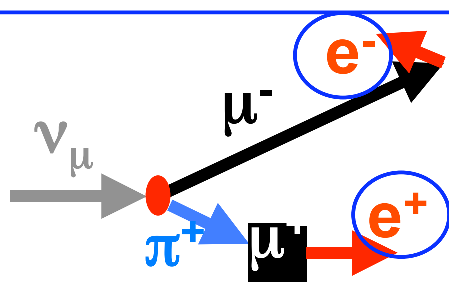
MiniBooNE results on the neutrino cross sections.

- Measurement of CC-1$\pi^{\pm}$ cross section.
  - Fermilab Wine&Cheese, Oct. 7th, 2005
- Measurement of NC-1π^0 cross section
  - Ph.D. thesis, J.L. Raaf







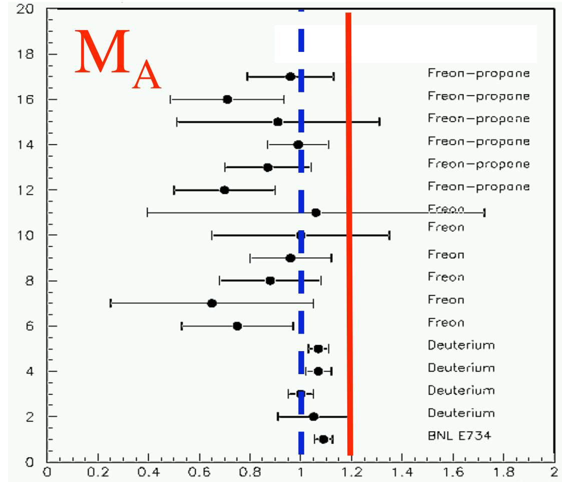


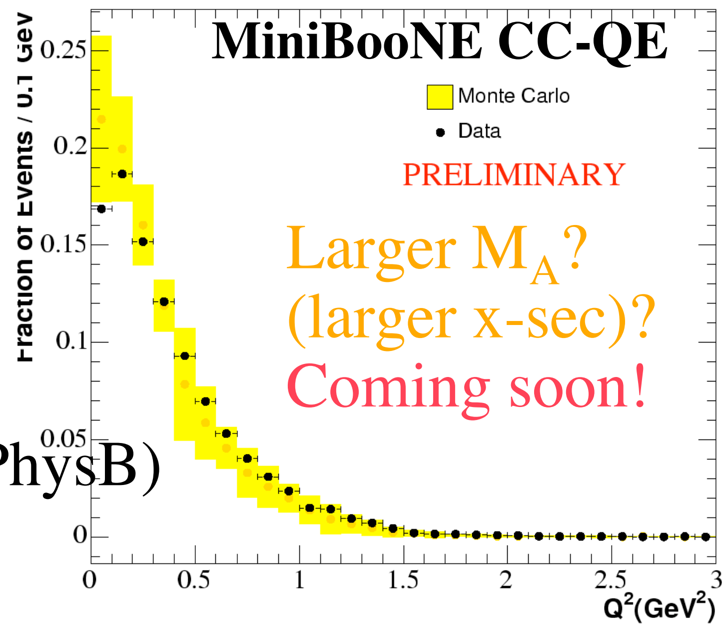
More results are expected from both K2K and MiniBooNE

- CC-QE
  - Cross Section and Axial Mass (M_A)

  M_A=1.18±0.03±0.12 (K2K-SciFi preliminary)
- CC-$1\pi^{\pm}$
  - Cross Section and $M_A^{1\pi}$
- CC-$1\pi^0$
- Beam ν_e flux
- NC-coherent π^0
- HARP results

  w/ K2K and MiniBooNE collaborators
  - *Al* with 12.9 GeV (accepted by NuclPhysB)
  - *Be* with 8 GeV (will be soon)





What's missing from K2K and MiniBooNE Cross Section Measurements?

- Good Q^2 resolution to understand nuclear effects
  - Need true nuclear models in MCs
- Resonant/coherent separation for BG measurements
- Multiparticle final states
- Antineutrino Measurements
- Absolute σ measurements for non-QE channels

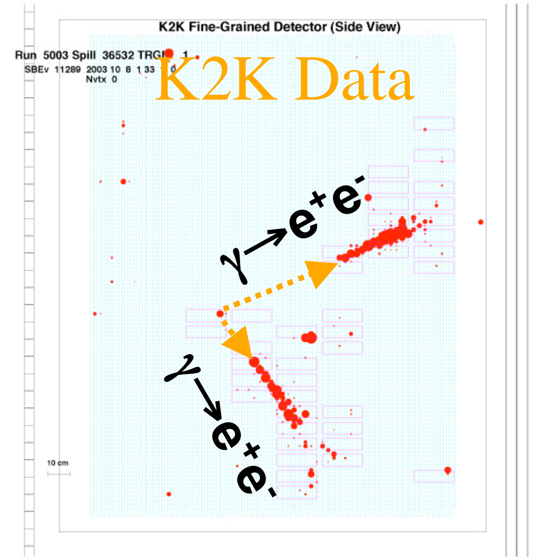
Needed to tune neutrino cross section Monte Carlos

All these needed for next generation oscillation measurements

3. SciBooNE Experiment

A fine-segmented tracking detector with an intense low energy neutrino beam.

- SciBar Detector
  - Well-working detector (2003.9- at K2K)
  - Fine granularity ($2.5 \times 1.3 cm^2$) and Fully-Active
  - PID capability
- FNAL-BNB
  - An intense and low energy (~1GeV) beam.
    - ≤ 1 year data taking is sufficient.
  - Both neutrinos and anti-neutrinos.
  - The beam is well-understood from hadron production experiments (HARP/BNL-E910).



An ideal marriage of the detector and the beam for a precision neutrino interaction experiment.

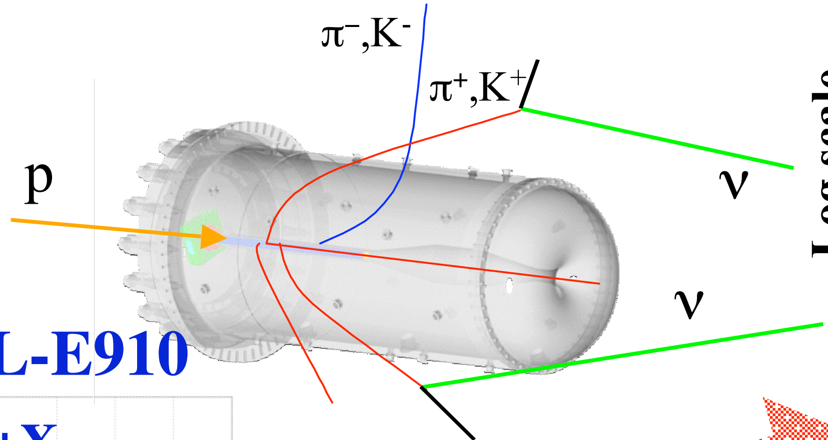
(A new experimental team from K2K and MiniBooNE)

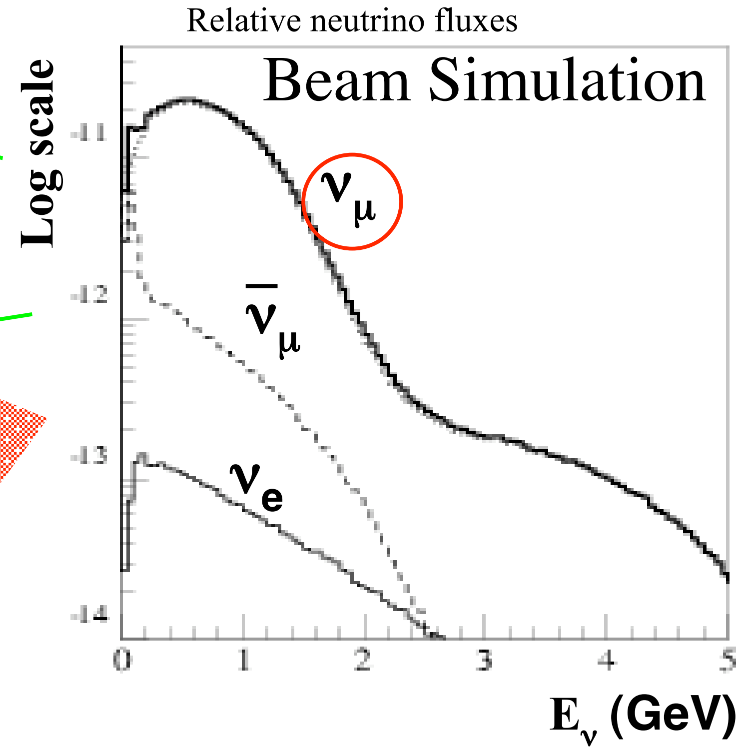
SciBooNE Overview

- Propose 2E20 POT run
  - 0.5E20 POT neutrino mode
  - 1.5E20 POT antineutrino mode
  - Not asking for concurrent running with MiniBooNE
- Propose construction of detector hall
- Director’s Review October, 2005
  - Concentrated on physics case
  - Answers to questions from Review will be shown throughout talk

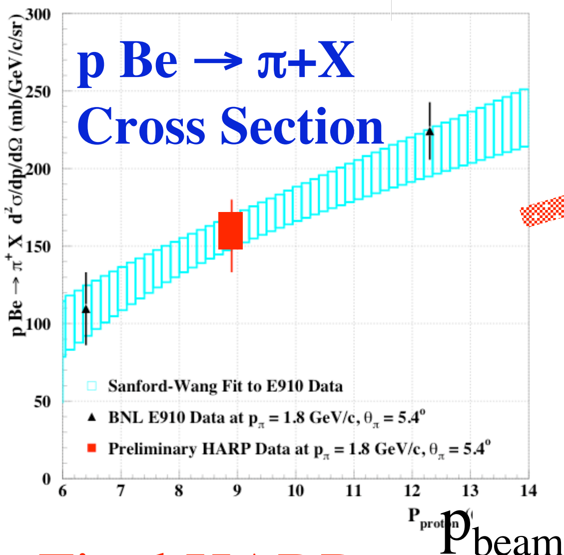
Fermilab Accelerator Complex and BNB (Booster Neutrino Beam)

FNAL BNB (2E20 protons for SciBooNE)

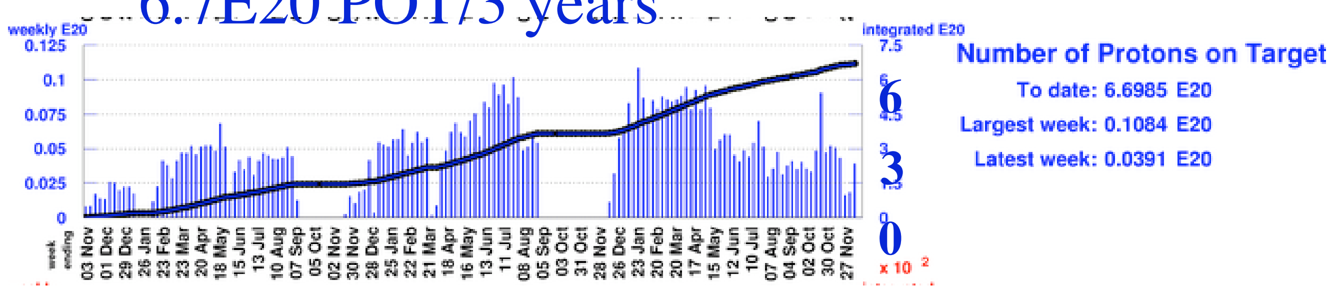




From BNL-E910



6.7E20 POT/3 years

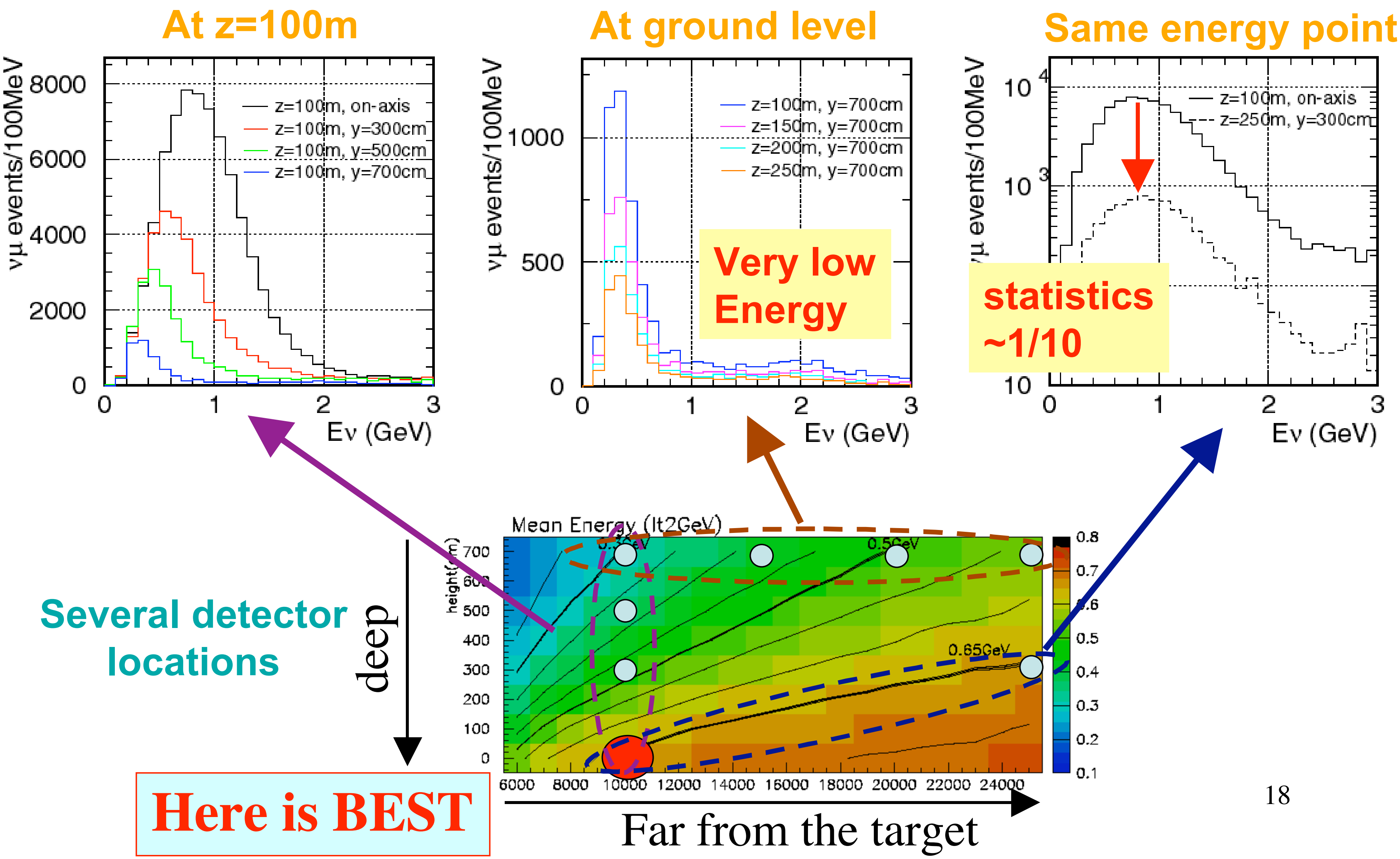


Final HARP results coming soon.

- Directorate recommends planning on 1-2E20 POT/year (Consistent with Proton Plan)

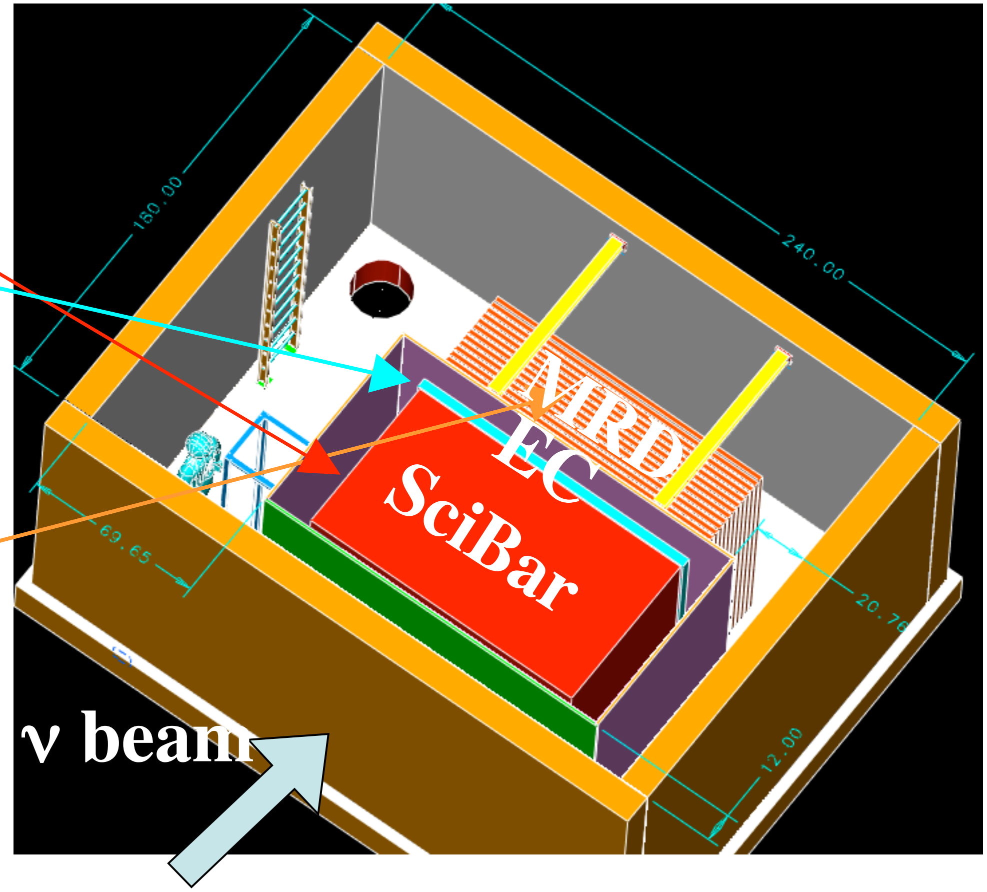
Ideal Detector Location

Expected ν_μ flux $\times$ σ spectra



Detector Components

- SciBar Detector
  - From KEK, Japan
- Electron Calorimeter
  - From KEK, Japan
  - European collaborators have responsibility.
- Muon Range Detector (MRD)
  - Will be built at FNAL from the parts of an old experiment (FNAL-E605).
  - The materials exist (except light guides) and detailed design is underway at FNAL.



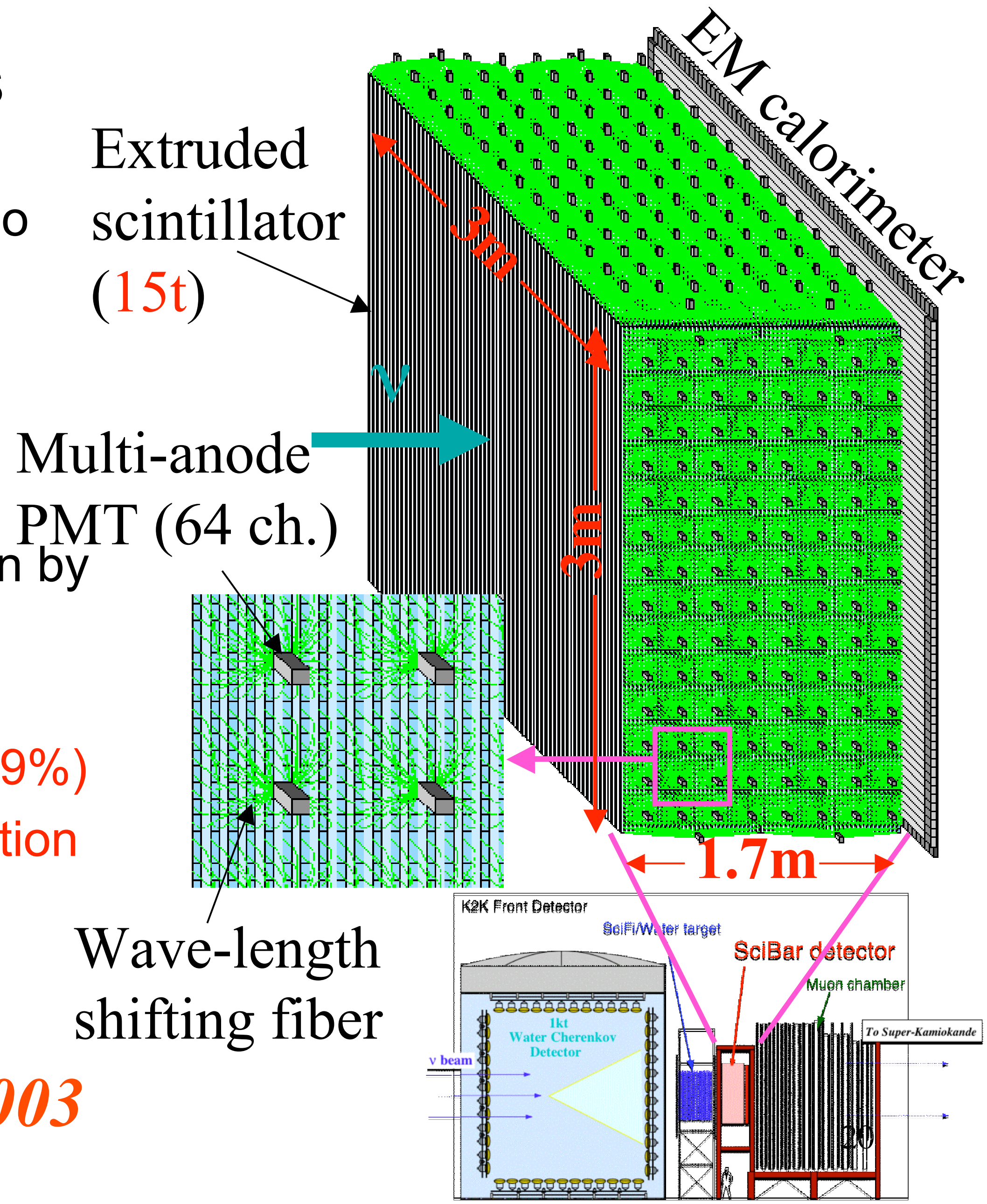
New engineering drawings since Review

SciBar Detector

- Extruded scintillators with WLS fiber readout
- The scintillators are the neutrino target
- 2.5 x 1.3 x 300 cm^3 cell
- ~15000 channels
- Detect short tracks (>8cm)
- Distinguish a proton from a pion by dE/dx
- Total 15 tons

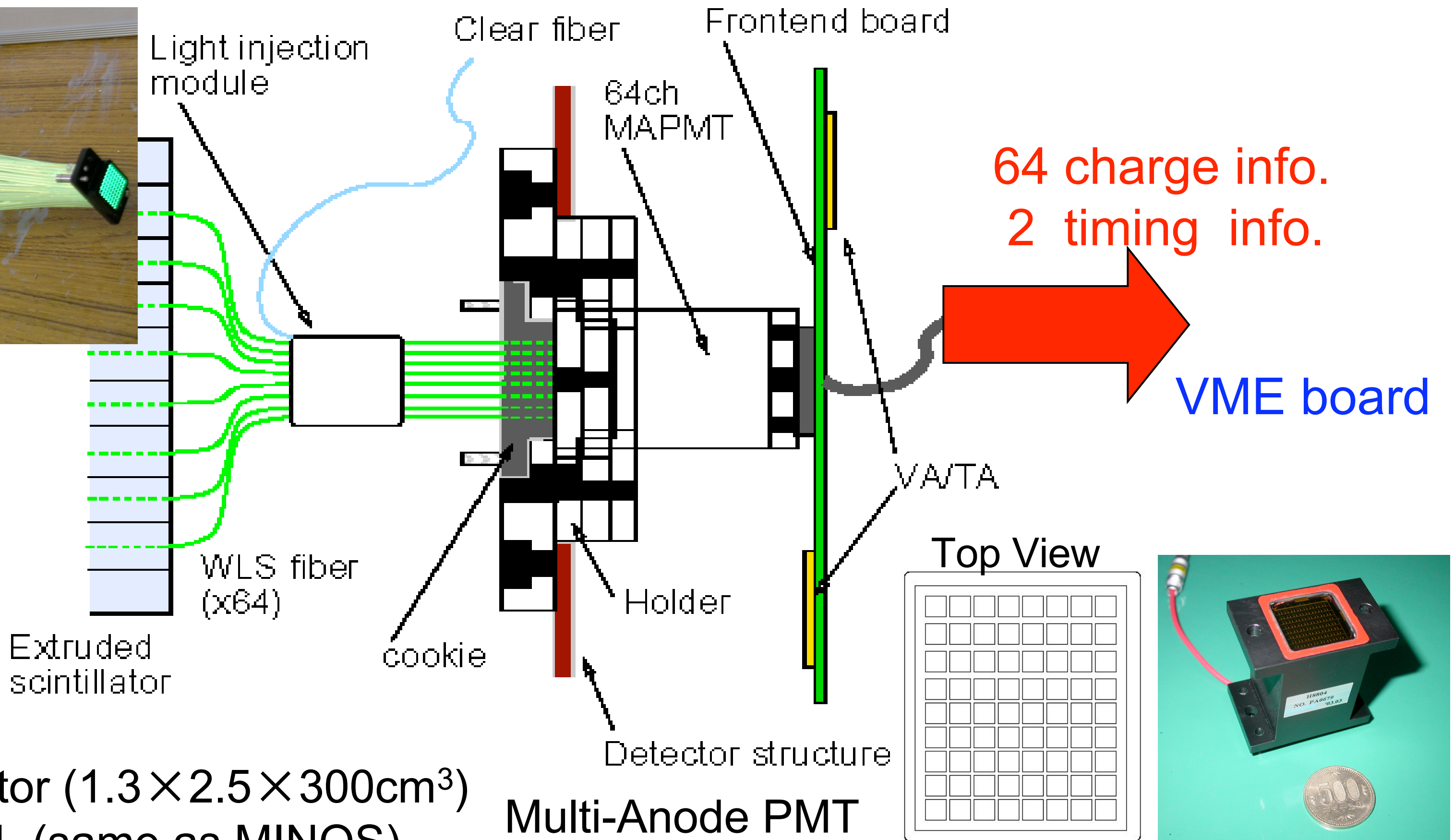
➔High track finding efficiency (>99%)

➔Clear identification of ν interaction process



Constructed in summer 2003

SciBar Components



Extruded Scintillator ($1.3 \times 2.5 \times 300cm^3$)
- made by FNAL (same as MINOS)

Wave length shifting fiber (1.5mmΦ)
- Long attenuation length (~350cm)

→ Light Yield : 18.9p.e./cm/MIP

Multi-Anode PMT
- $2 \times 2mm^2$ pixel (3% cross talk @1.5mmΦ)
- Gain Uniformity (20% RMS)
- Good linearity (~200p.e. @6×10^5)

Readout electronics with VA/TA
- ADC for all 14,400 channels
- TDC for 450 sets (32 channels-OR)

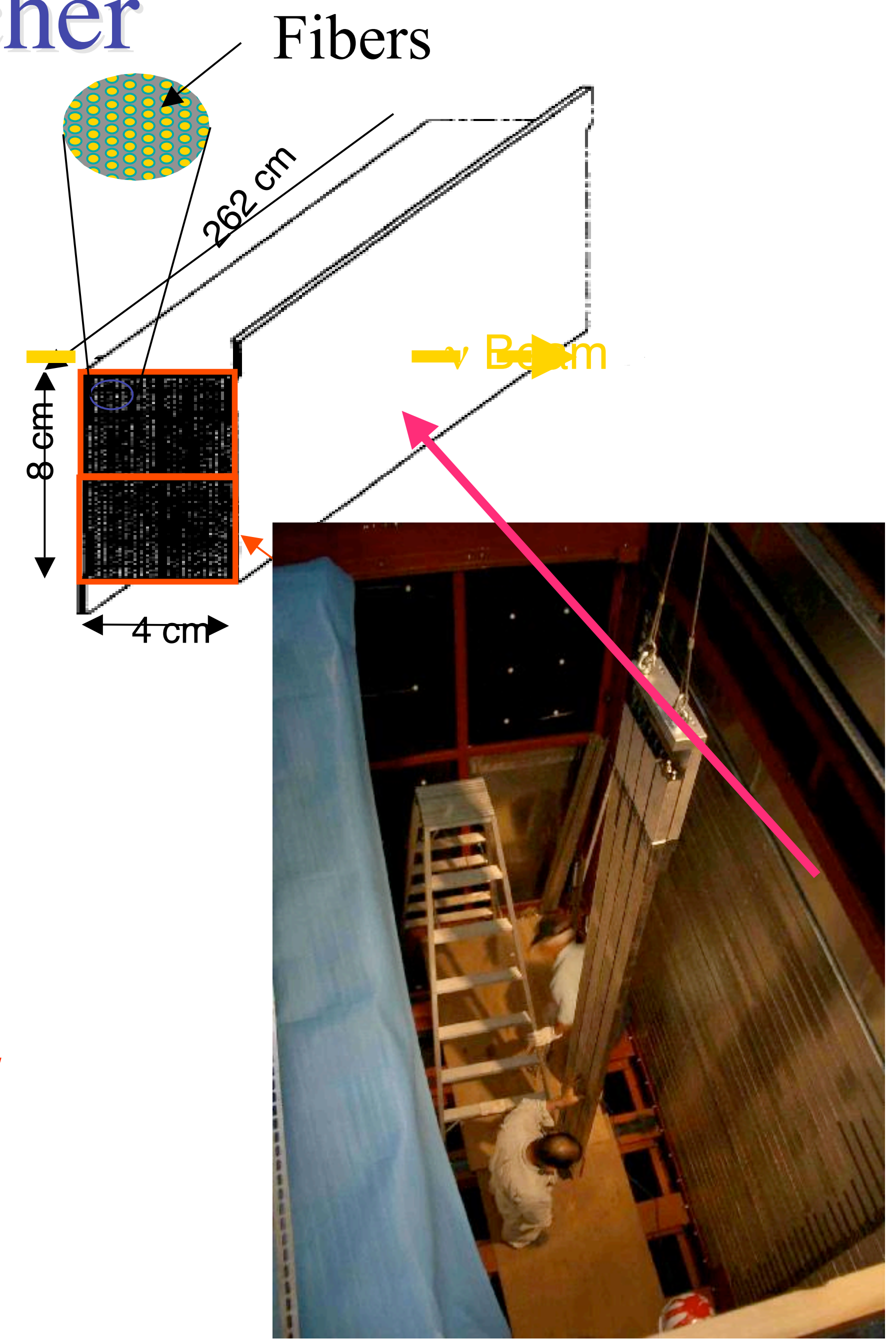
Electron Catcher

- “spaghetti” calorimeter re-used from CHORUS
- 1mm diameter fibers in the grooves of lead foils
- $4x4cm^2$ cell read out

  from both ends
- 2 planes (11X_0)

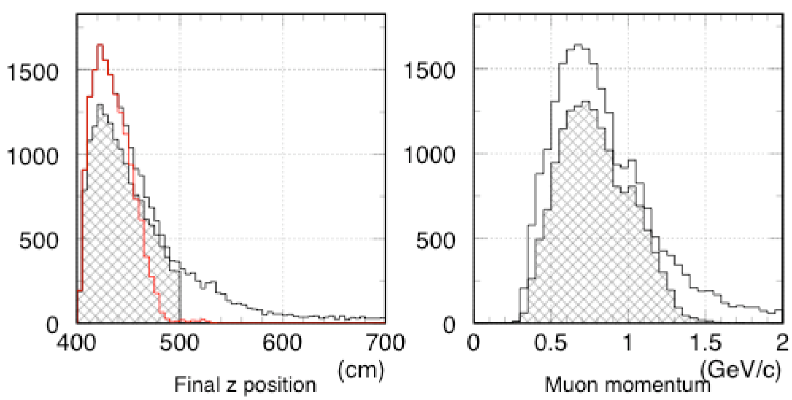
  Horizontal: 30 modules

  Vertical : 32 modules
- Expected resolution 14%/$\sqrt{E}$
- Linearity: better than 10%



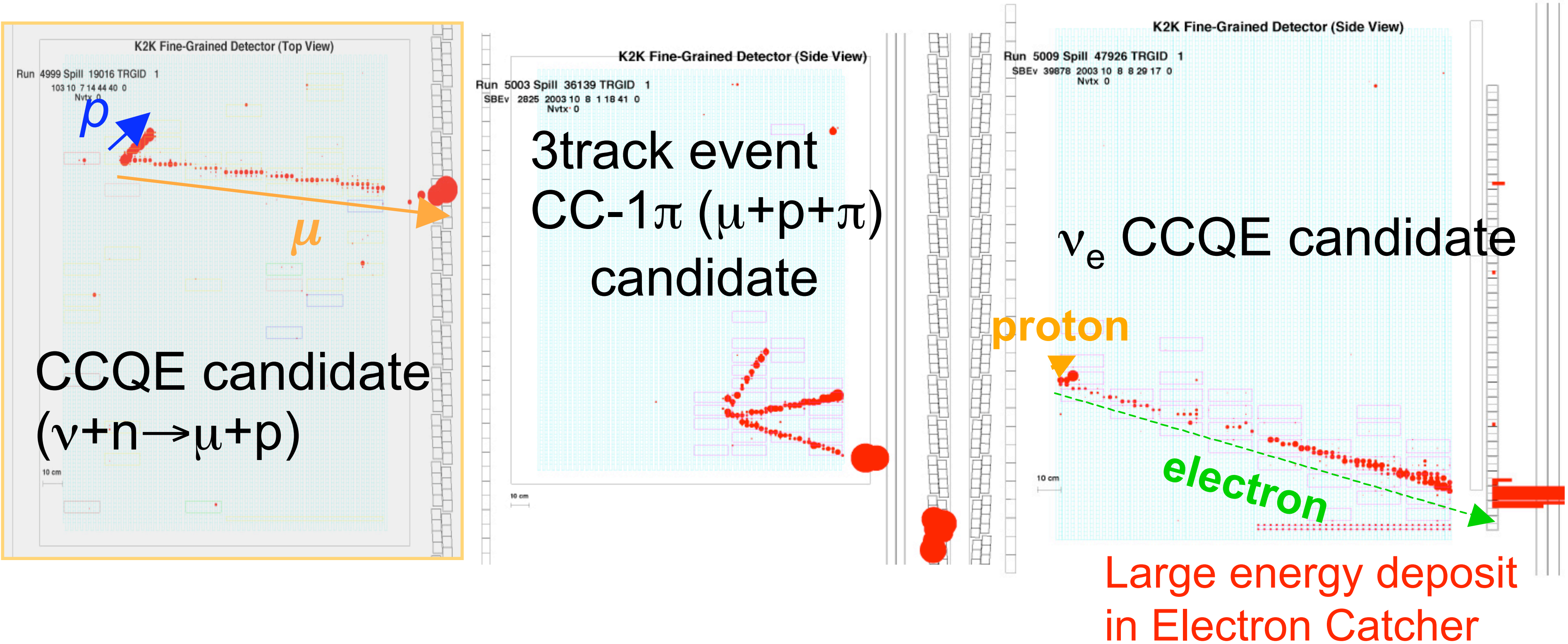
MRD

- Major Components
  - Have at Fermilab already:
    - Iron plates
      - 1”, 2” plates available
    - Scintillators
      - Very good condition
    - PMTs
    - Electronics
    - Cables
    - Power supplies
  - Need to be fabricated
    - Light guides
- Improved design and inventory since Review
  - Thank you Mechanical Dept!



MRD Acceptance: Final z position and momentum of stopping μs

Event Display (K2K- Data)



- The neutrino events are well observed with fine resolution
  – Good final state particle ID

4. Physics of SciBooNE

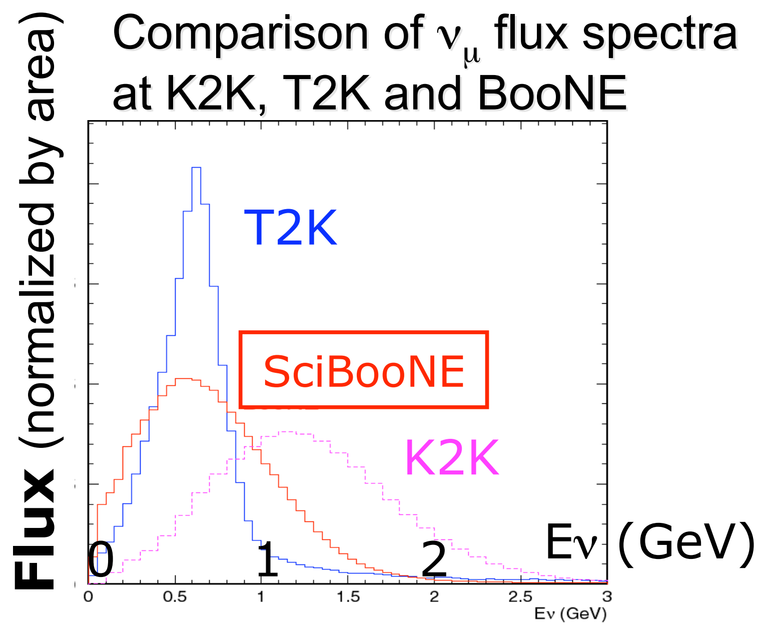
Neutrino run (0.5×10^{20} POT)

\# of interactions
in 10 ton Fiducial Volume
ν_μ **~78,000**
ν_e~ **700**

cf. K2K-SciBar (0.2×10^{20} POT) : ~25,000 ν_μ

The following studies use K2K's well developed MC and analysis tools, and MiniBooNE's well developed beam MC.

Neutrino Run

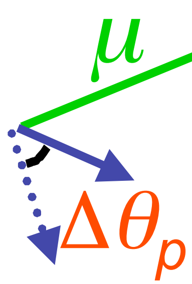


- Measurements
  - CC-1π cross section
  - CCQE σ,M_A measurement
  - NC π^0 measurement
  - Search for CC coherent π
  - Search for NC coherent π^0
  - Search for radiative Delta decay (ν+N$\rightarrow\mu$+N'+γ)
  - Intrinsic ν_e flux for BNB ($\nu_\mu \rightarrow \nu_e$ appearance search)
  - Unoscillated $\Phi_\nu \times \sigma$ for BNB ($\nu_\mu \rightarrow \nu_\mu$ disappearance search)

Cross checks

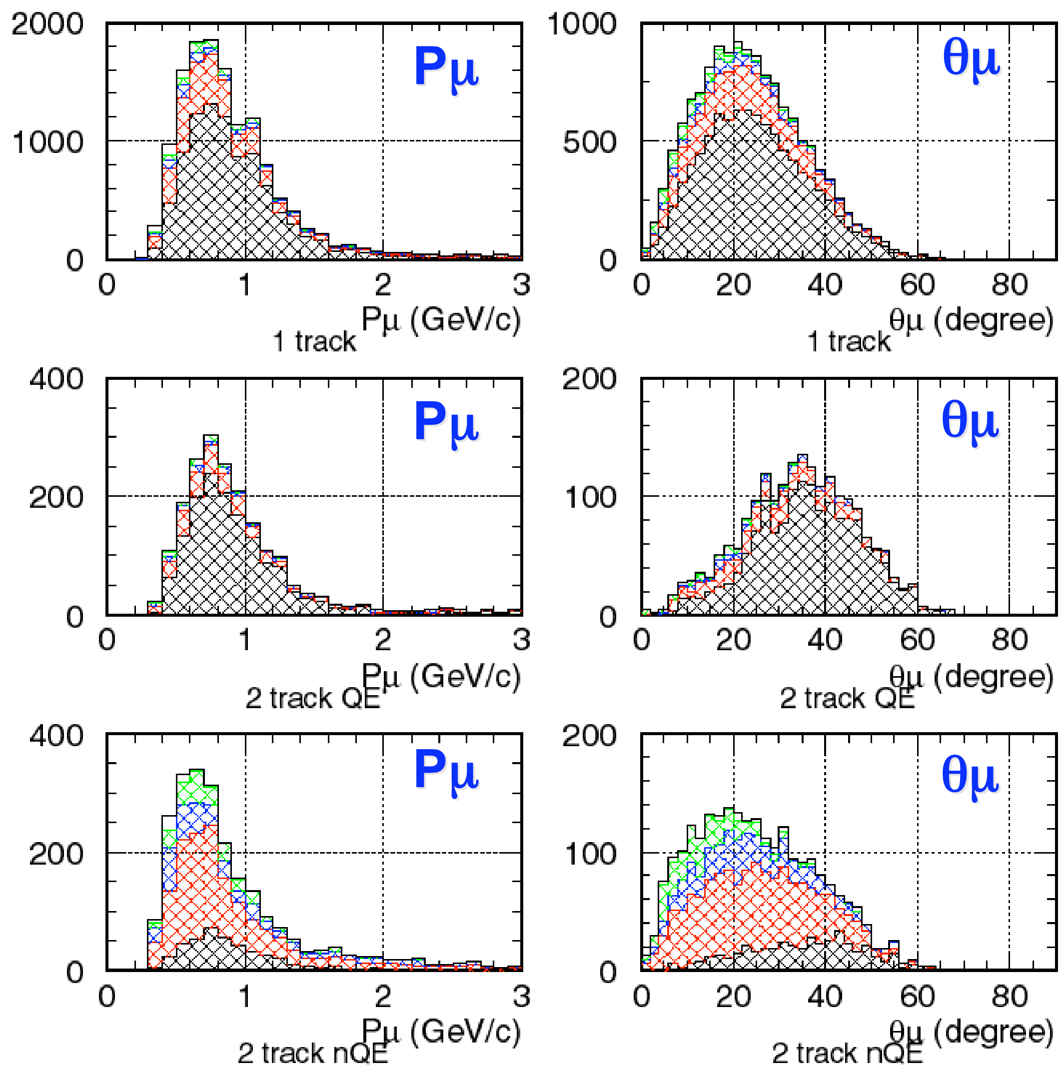
Study ν interactions to improve MC modeling of low E νs for precision physics

CC Event Selection with MRD matching



Expected direction assuming CCQE

CC-QE
CC-1π
CC-coh. π
CC-multi π



1 track

~13,500 events
QE~67%

2 track QE

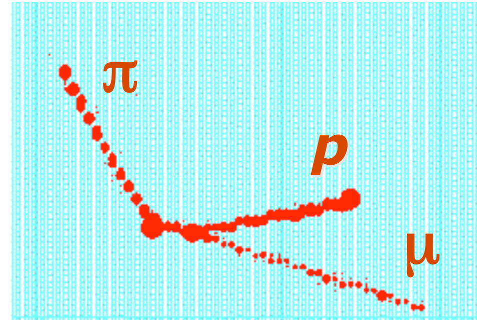
~1,970 events
QE~76%

2 track non-QE

~2,360 events
CC-1π~49%

CC-1π^+ measurement

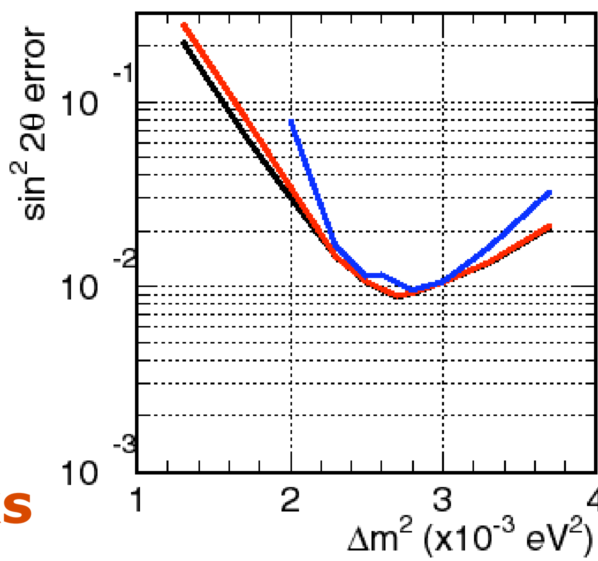
- Non-QE events: dominant background for ν_μ disappearance
  - At BNB energies, non-QE BG dominated by CC1π^+
  - T2K needs uncertainty of nonQE/QE to ~5%



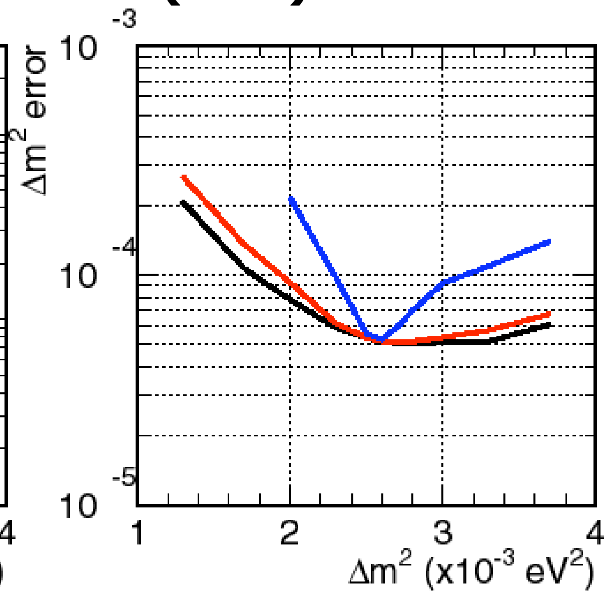
ν_μ disappearance measurement error (90%CL)

— stat. only
— δ(nQE/QE)= 5%
— δ(nQE/QE)=20%

$\delta(\sin^2 2\theta)$



$\delta(\Delta m^2)$



CC-1π^+ signature:
2 MIP-like tracks

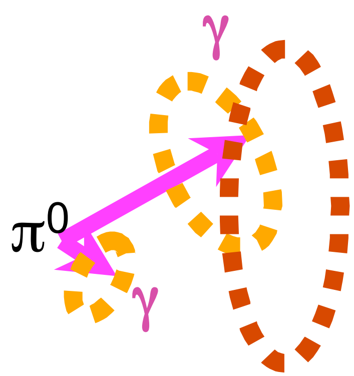
Vertex activity cuts:
separate $\nu+p\rightarrow\mu^- p\pi^+$
from $\nu+n\rightarrow\mu^+ n\pi^+$

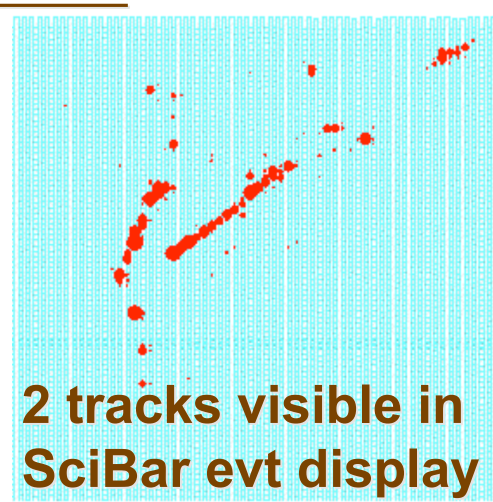
Statistics and systematics
Sufficient for ~5% measurement

NC-1π^0 measurement

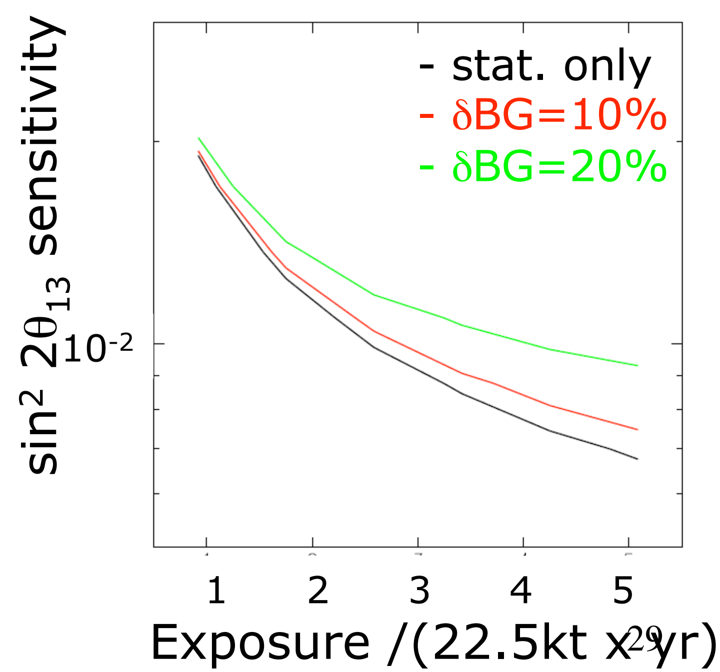
- Dominant background to ν_e appearance in any experiment
  - Overlapping rings, or back-to-back decay
  - T2K needs NC1π^0 cross section to be known to 10% level

2-ring merged to 1-ring in Cherenkov detector

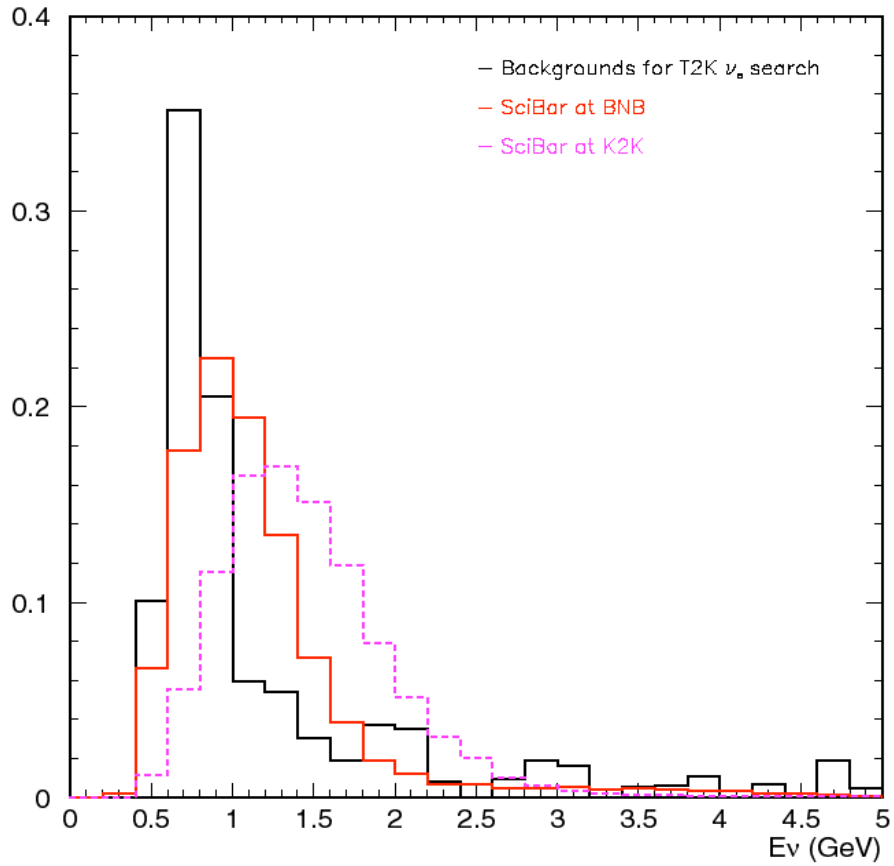




200~700MeV/c π^0s



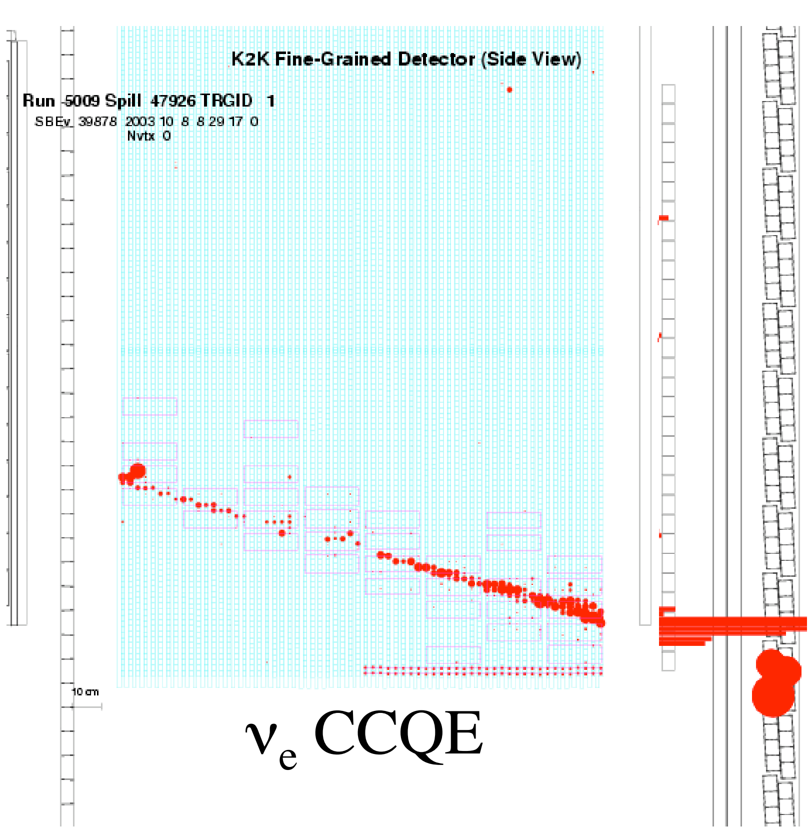
NC-1π^0 measurement (cont'd)



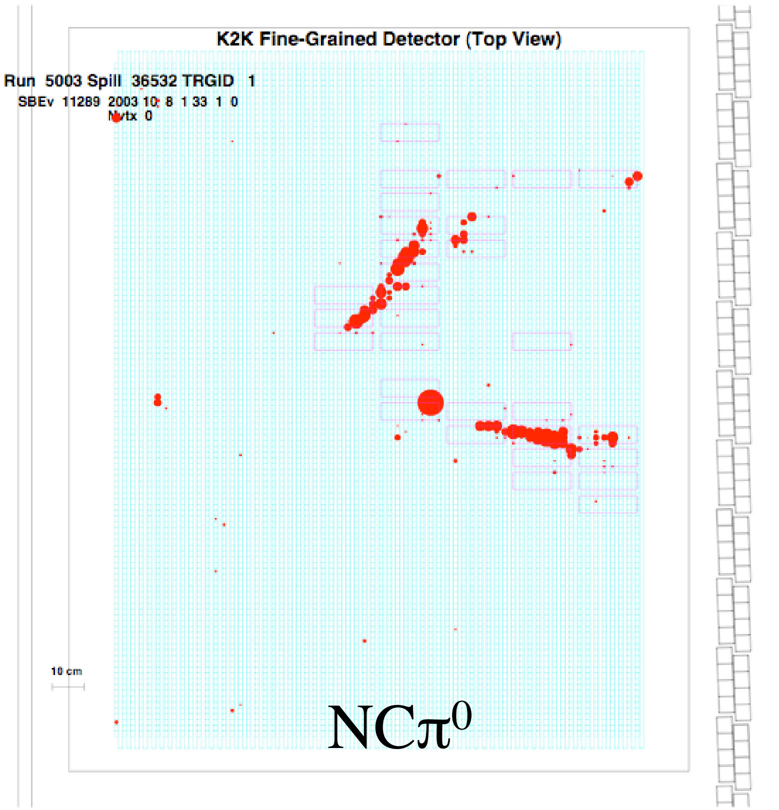
SciBooNE expects to make a 10% measurement

Measurement at energy that is crucial for T2K NC1π^0 BGs

BNB Intrinsic ν_e Measurement



ν_e CCQE



$NC\pi^0$

- Electron catcher provides good electromagnetic ID and energy resolution
  - Can use dE/dx in SciBar as well
- Expect to directly measure ν_e flux to 10-20% in ν mode
  - Assuming current efficiency/purity

Anti-neutrino run (1.5×10^{20} POT)

of interactions in FV

$\bar{\nu}_\mu$ **~40,000**

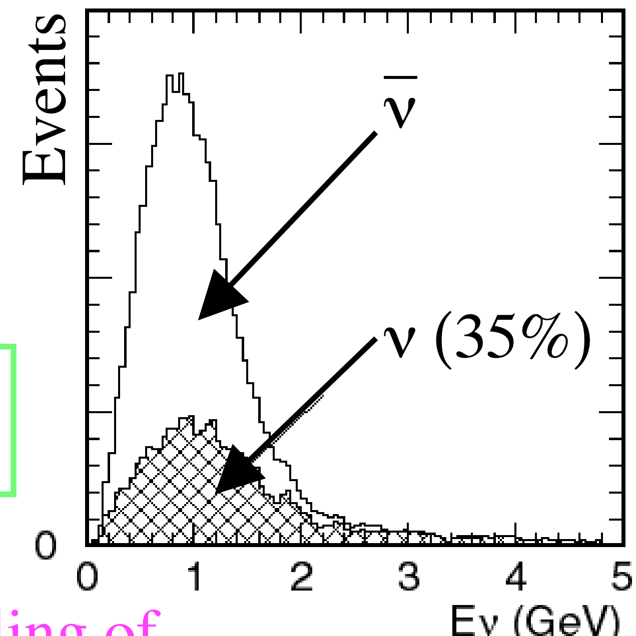
ν_μ **~22,000**

cf. K2K-SciBar No data!

Again, well-developed analysis and MC software are used for these studies, and MiniBooNE's well-developed neutrino beam MC.

- $\bar{\nu}$ Measurements
  - CCQE measurement.
    - Negligible BG from ν.
    - Energy Dependence of σ and M_A
  - CC-1π cross section with M_A.
  - NC π^0 measurement
    - Also $\nu+p \rightarrow \nu+p+\pi^0$ exclusive final-state search
  - Search for CC coherent π
  - Search for NC coherent π^0
  - Search for radiative Delta decay ($\nu+N \rightarrow \mu+N'+\gamma$)
  - Hyperon production in anti-ν mode
  - Energy dependence of ν contamination of BNB anti-ν mode.

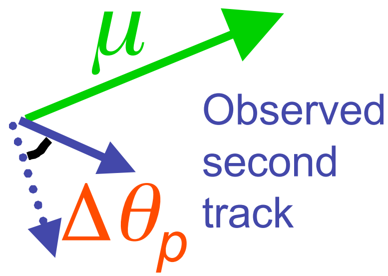
Reversible current horn



Study ν interactions to improve MC modeling of low E νs for precision physics

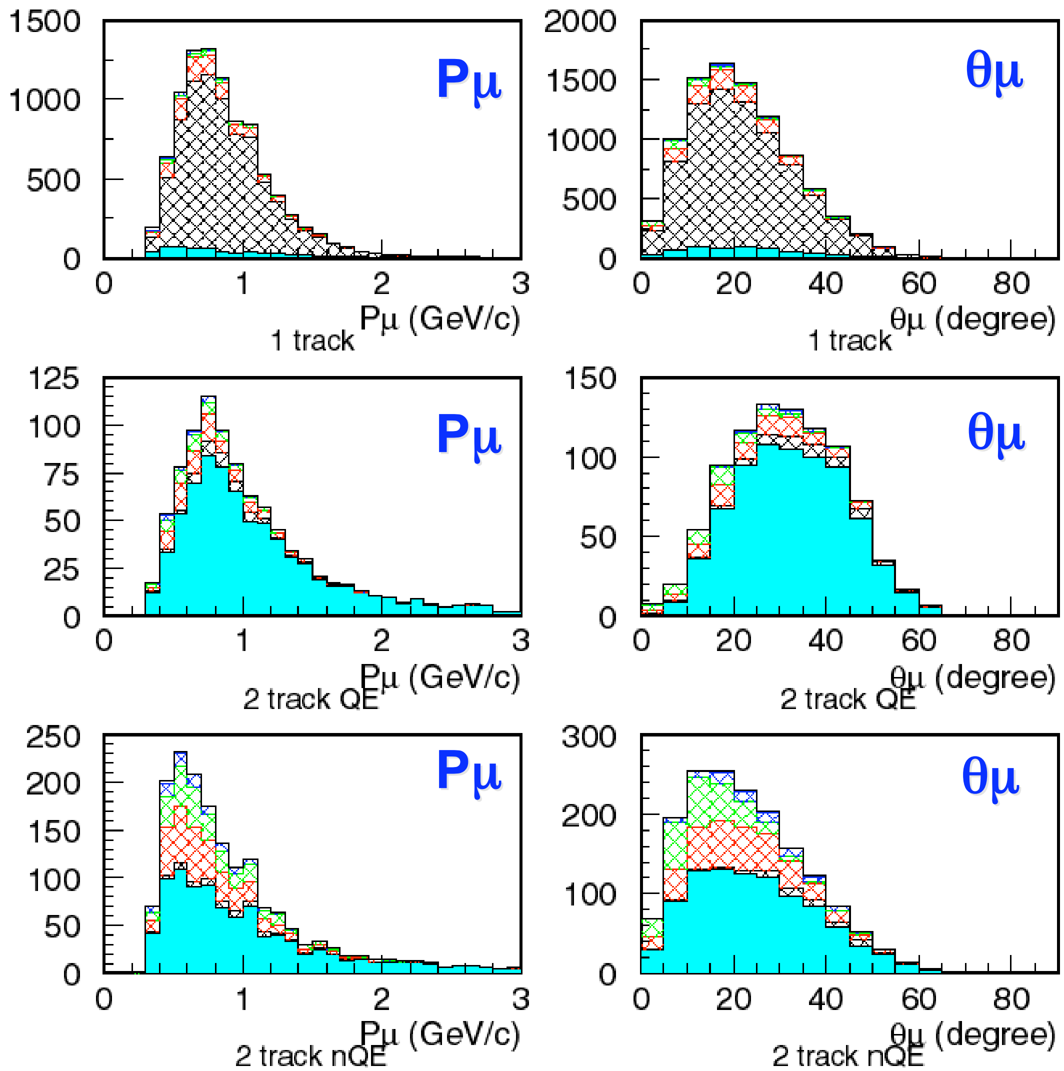
Identifying CC Events (w/MRD)

w/ vertex activity cut



Expected direction
assuming CCQE

CC-QE
CC-1π
CC-coh. π
CC-multi π
ν_μ BG



1 track

~9,300 events
QE~80%
ν_μ BG=7%

2 track QE

~910 events
ν_μ BG~80%

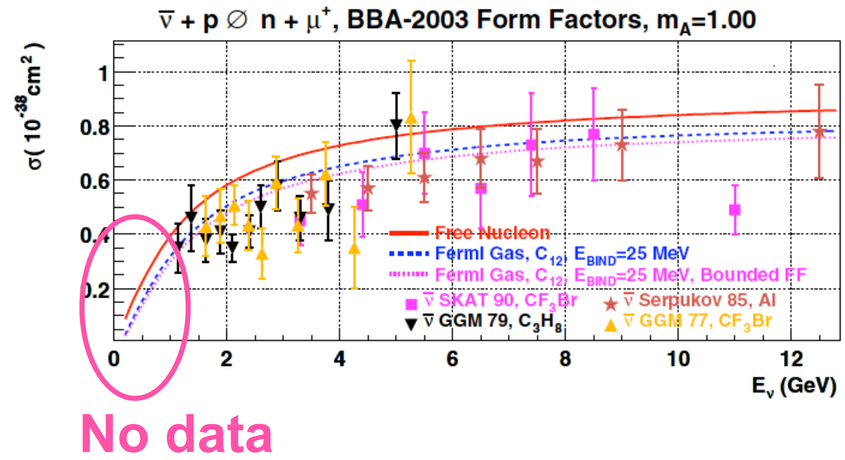
2 track non-QE

~1,700 events
ν_μ BG~56%
CC-1π~21%
CC-coh. π~15%

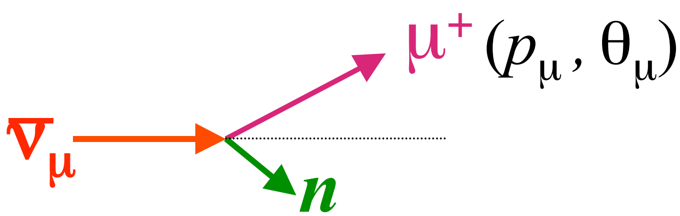
Antineutrino CCQE measurement

Physics motivation

- Important for T2K phase-II
  - CP violation search
- Free proton scattering: check of nuclear model



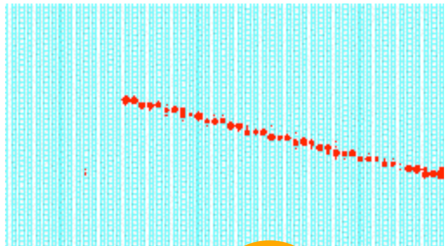
CC-QE: $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$

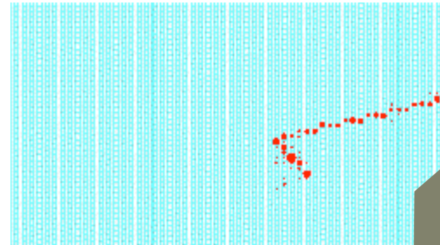


- **Detected as a 1-track event in SciBar**
- **Excellent ν energy, Q^2 resolution**

- Expect ~9,000 CCQE events after cuts, 80% purity

BNB Wrong Sign Backgrounds





Right Sign

$\bar{\nu}+p \rightarrow \mu^{+}+n$

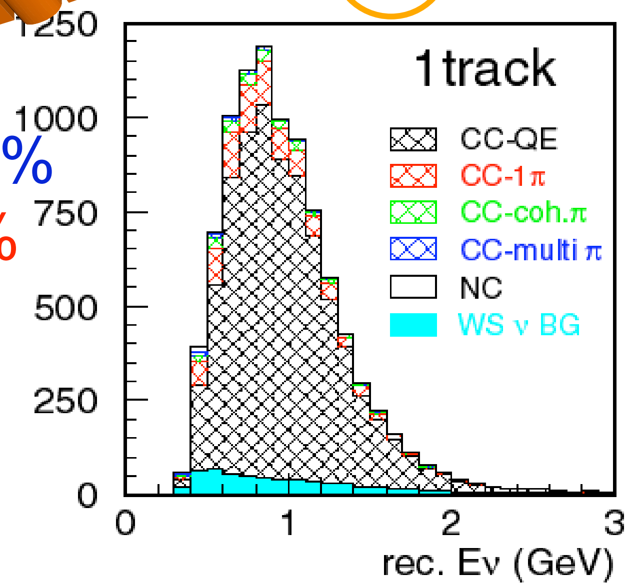
$\bar{\nu}$ QE: ~80%

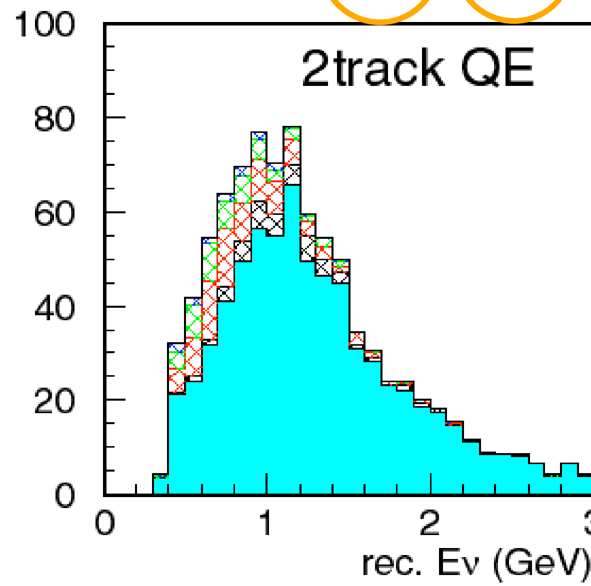
ν BG: ~7%

Wrong Sign

$\nu+n \rightarrow \mu^{-}+p$

ν QE: ~80%

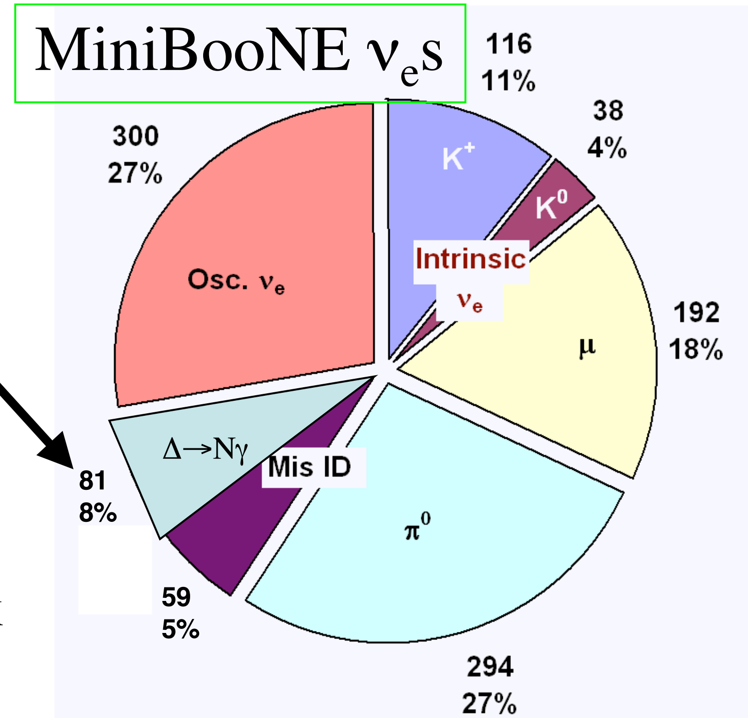


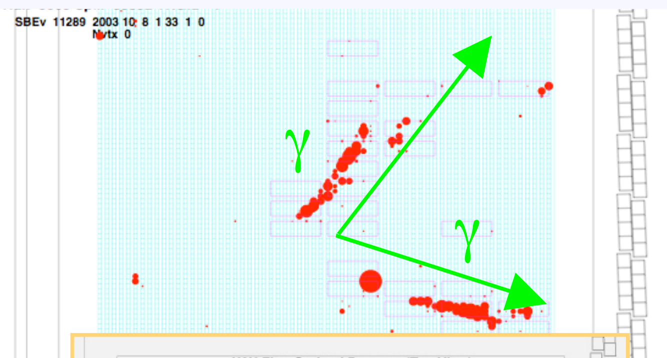


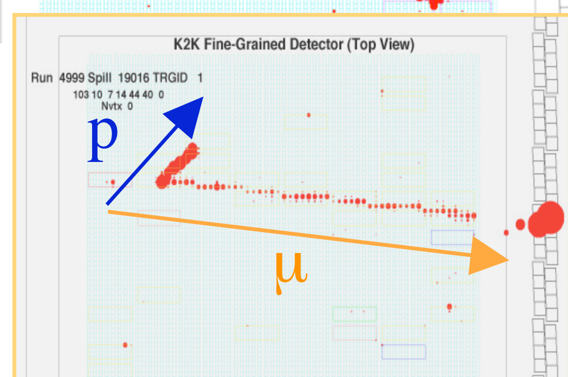
- MB: ~15% uncertainty on WS BG in 4 bins (0-1.5 GeV)
- SB: ~7.5% stat. err. in 2 track sample in 4 bins (0-1.5 GeV)

Radiative Δ Decay

- $\Delta \rightarrow N\gamma$ is a background for $\bar{\nu}_e, \nu_e$ appearance (NOνA too!)
  - BR: 15% uncertainty
  - Never measured in ν production
- Event signature
  - NC: recoil proton and detached photon track
  - CC: muon and recoil proton with shared vertex and photon with detached vertex
  - Each case: photon and proton tracks should be consistent with decay of Δ mass particle
  - π^0s provide calibration sample for photon tracks
- Expect ~ 45 events after cuts in total run (ν and $\bar{\nu}$ mode)
- Would be first observation of neutrino induced Δ radiative decay
  - Very powerful detector!







- Anti-ν run
  - CCQE measurement.
    - Negligible BG from ν.
    - Energy Dependence of σ and M_A
  - CC-1π cross section with M_A.
  - NC π^0 measurement
    - Also $\bar{\nu}+p\rightarrow\bar{\nu}+p+\pi^0$ exclusive final-state search
  - Search for CC coherent π
  - Search for NC coherent π^0
  - Search for radiative Delta decay ($\bar{\nu}+N\rightarrow\mu$ ($\bar{\nu}$)$+N'+\gamma$)
  - Hyperon production in anti-ν mode
  - ν contamination for BNB anti-ν measurements.

No Measurements Currently Exist

MiniBooNE will run in $\bar{\nu}$ mode in 2006

SciBooNE's final state resolution capability enhances σ physics reach

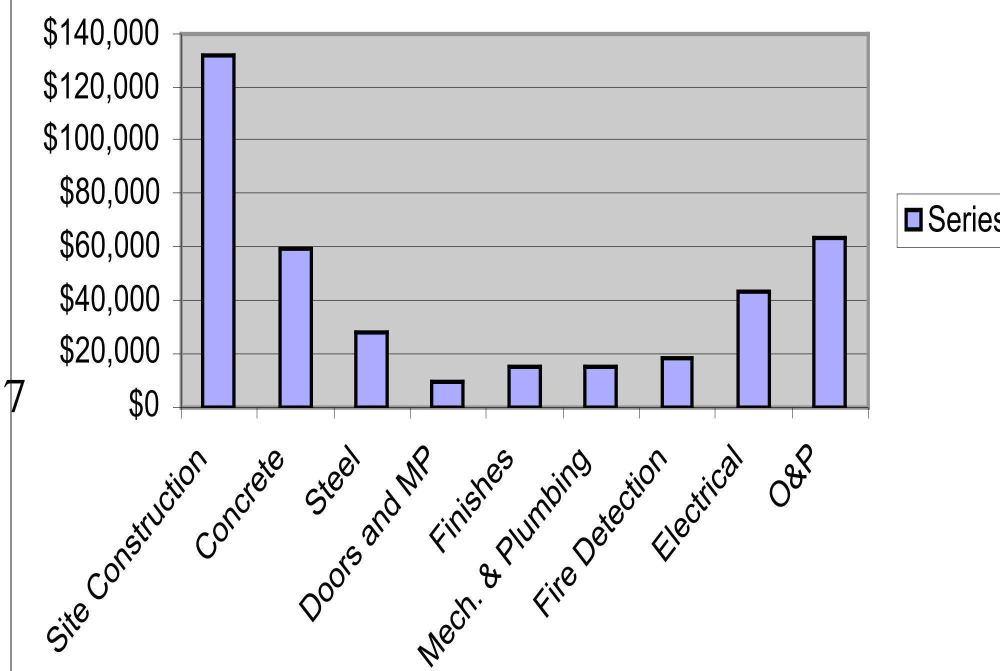
5. Logistics

- Schedule
  - Disassemble detector: Jan 2006
  - Ship detector: Feb/Mar, 2006 (depends on money)
  - Civil construction: Jan-September, 2006
    - Schedule from FESS report
    - Bid: Jan-May, 2006
    - Construction June-September, 2006
  - Reassemble detector: March-June, 2006
  - Installation : September 2006
  - Commissioning: September/October, 2006
  - Beam data: October, 2006

All Done Before

Need prompt approval to enact aggressive schedule

Costs



- Civil Construction
  - $648,576
  - "bottoms up" estimate completed.
  - Anticipated Contract Price $381,417
  - Contingency = 20%
- PPD Impact
  - M&S
    - $60,200 (all departments)
    - $20-50,000 for optical fibers/cookies (light guides) - university groups?
  - Personnel: ~3 FTE (normalized to one year)
- AD Impact - power bill
  - $220,000 incremental cost increase (Booster for 8 GeV line)
  - $67,000 power downstream of Booster (8 GeV line/target)
- CD Impact
  - PREP (electronics pool) equipment
  - Modest computing resources needed

Thanks to Steve Dixon
And Tom Lackowski, FESS

Cost Considerations

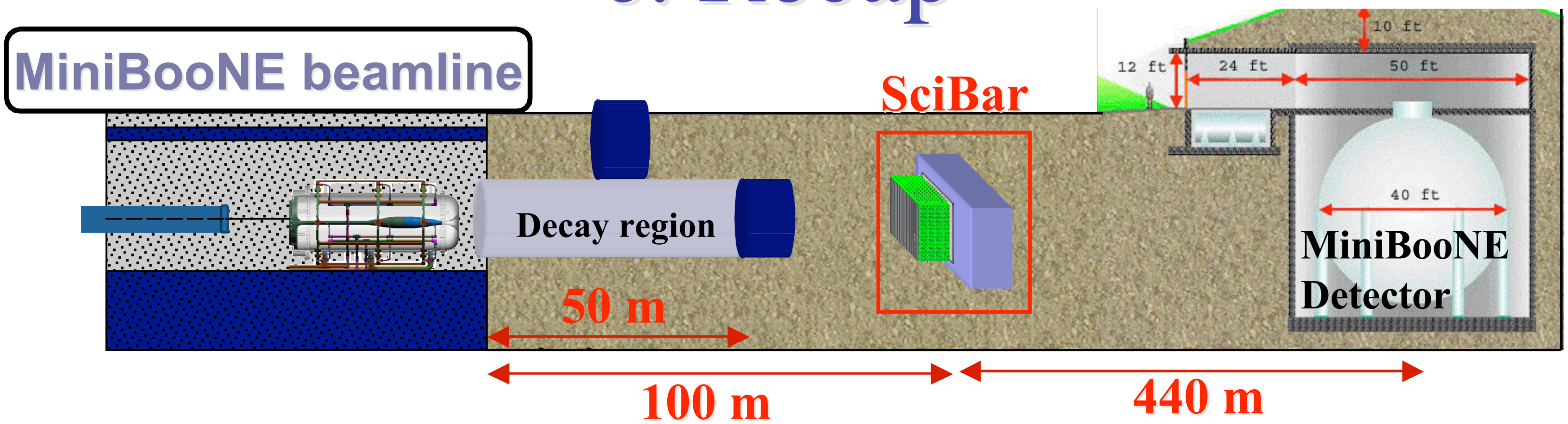
- Beam is already built and commissioned!
- Cost of SciBar ~ \$3M
- Cost of Electron Catcher ~ \$1M
- Cost of shipping ~ \$50k
- University groups will contribute significant funds and personnel

Free to FNAL

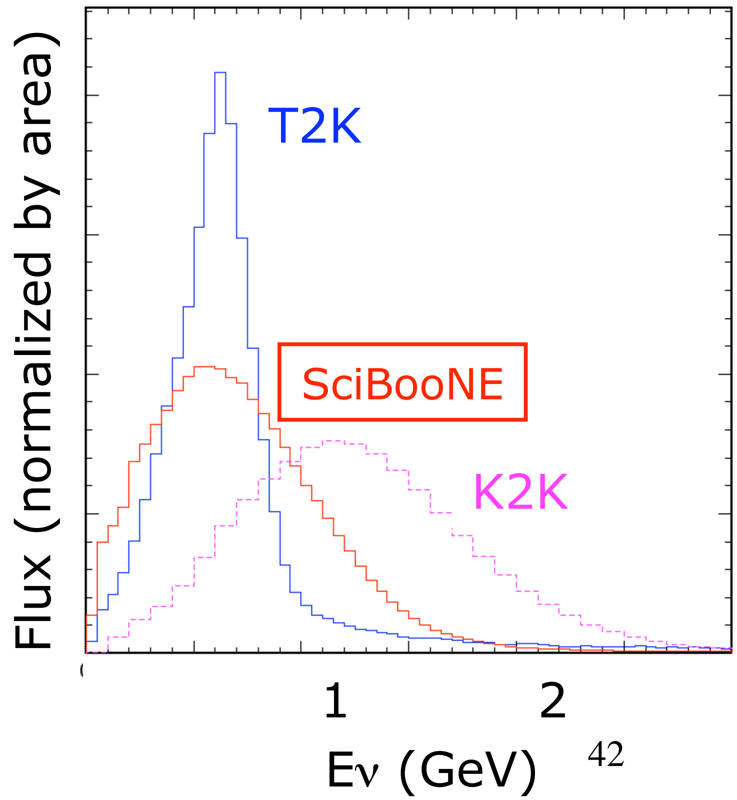
- Cost of civil construction \$650k
- Cost of running BNB for 1 year ~\$300k
- Cost of FNAL M&S <\$100k

Small additional investment
for a lot of physics output!

6. Recap



- Combine well developed detector with well understood running beam
  - Short timescales and modest cost
- Precise knowledge of σs necessary for T2K and other experiments
  - Non quasi-elastic ν interactions
- MiniBooNE near detector.
  - Confirmation, redundancy for BNB νs
- Antineutrinos
  - Currently unexplored physics territory.



Conclusions

- SciBar is a working detector with excellent capabilities
- The BNB is a well-understood running ν beam
- Can contribute to near-term neutrino program at FNAL
  - Complementary to MINERνA
  - Bring more neutrino physicists to FNAL
- Many recent surprises in ν interactions at ~1 GeV
  - Nuclear targets have unpredicted effects on neutrino event kinematics
  - Cross sections (and therefore event rates) differ from predictions
    - Different rates of signal and BG events
      - Flavor BGs and ν-interaction BGs
- What other surprises await?
- **We ask the PAC to approve our proposal to build a detector enclosure, and our 2E20 POT run**
  - Prompt approval needed to secure funding for university groups and U.S./Japan Research Fund

Backup

Thoughts on ν_μ Signal and BG σs

- Oscillation expts use CCQE events on nuclear targets for signal
  - Nuclear targeta provide more interactions, better statistics
  - Simple kinematics $\Rightarrow$ good energy reconstruction
- ν_e Appearance
  - Need to distinguish e from μ in detector
  - BG = processes that fake ν_e oscillation signals (flavor BG)
    - Intrinsic νe
    - NCπ0
    - NCΔ decay
  - Affect counting experiment
- ν_μ Disappearance
  - Need to distinguish CCQE from other CC processes
  - BG = processes that fake QE signal (ν-interaction BG)
    - CC1π+
  - Affect energy fitting experiment (poor energy resolution)
- Note: CCQE BG processes also affect νe searches!

Past Cross Section Uncertainty Table

Type	***Cross Sec.***	***E<1 GeV***	***E>1 GeV***	***Role***
ν_μ	CCQE	>15-20%	15-20%	$\nu_\mu(\nu_e)$ signal
ν_μ	$CC1\pi^+$(res)	~25%	~25%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	$CC1\pi^+$(coh)	100%	~30%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	$NC1\pi^0$(res)	~30%	~30%	ν_e BG(#,E)
ν_μ	$NC1\pi^0$(coh)	No data!	~30%	ν_e BG(#,E)
$\bar{\nu}_\mu$	CCQE	No data!	15-20%	$\bar{\nu}_\mu$ $(\bar{\nu}_e)$ signal
$\bar{\nu}_\mu$	$CC1\pi^-$(res)	No data!	~25-30%	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	$CC1\pi^-$(coh)	No data!	No data!	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	$NC1\pi^0$(res)	No data!	25%	$\bar{\nu}_e$ BG (#,E)
$\bar{\nu}_\mu$	$NC1\pi^0$(coh)	No data!	30%	$\bar{\nu}_e$ BG (#,E)

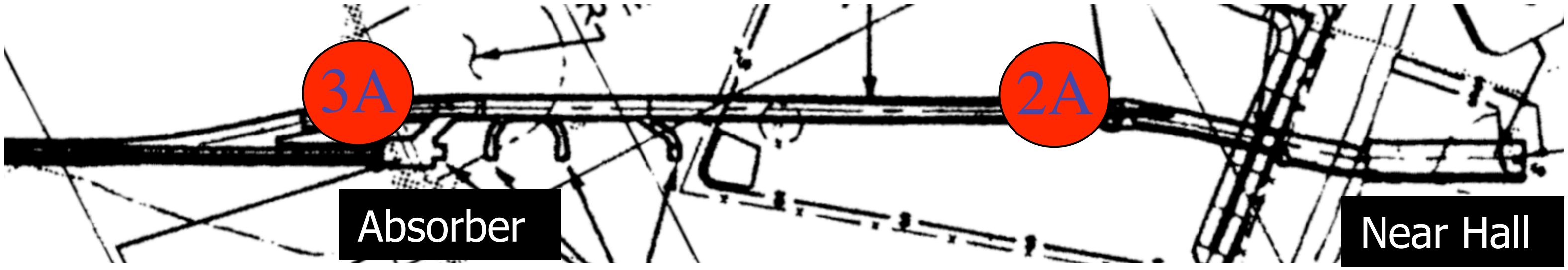
Current Cross Section Uncertainty Table

Type	*Cross Sec.*	*E<1 GeV*	*E>1 GeV*	*Role*
ν_μ	CCQE	~10%(MB)	~15%(K2K)	$\nu_\mu(\nu_e)$ signal
ν_μ	$CC1\pi^+$(res)	~15%(MB)	~25%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	$CC1\pi^+$(coh)	~50%(MB)	~15%(K2K	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	$NC1\pi^0$(res)	~20%(MB)	~20%(K2K)	ν_e BG(#,E)
ν_μ	$NC1\pi^0$(coh)	~50%(MB)	~30%	ν_e BG(#,E)
$\bar{\nu}_\mu$	CCQE	No data!	15-20%	$\bar{\nu}_\mu$ ($\bar{\nu}_e$) signal
$\bar{\nu}_\mu$	$CC1\pi^-$(res)	No data!	~25-30%	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	$CC1\pi^-$(coh)	No data!	No data!	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	$NC1\pi^0$(res)	No data!	25%	$\bar{\nu}_e$ BG (#,E)
$\bar{\nu}_\mu$	$NC1\pi^0$(coh)	No data!	30%	$\bar{\nu}_e$ BG (#,E)

Future Cross Section Uncertainty Table

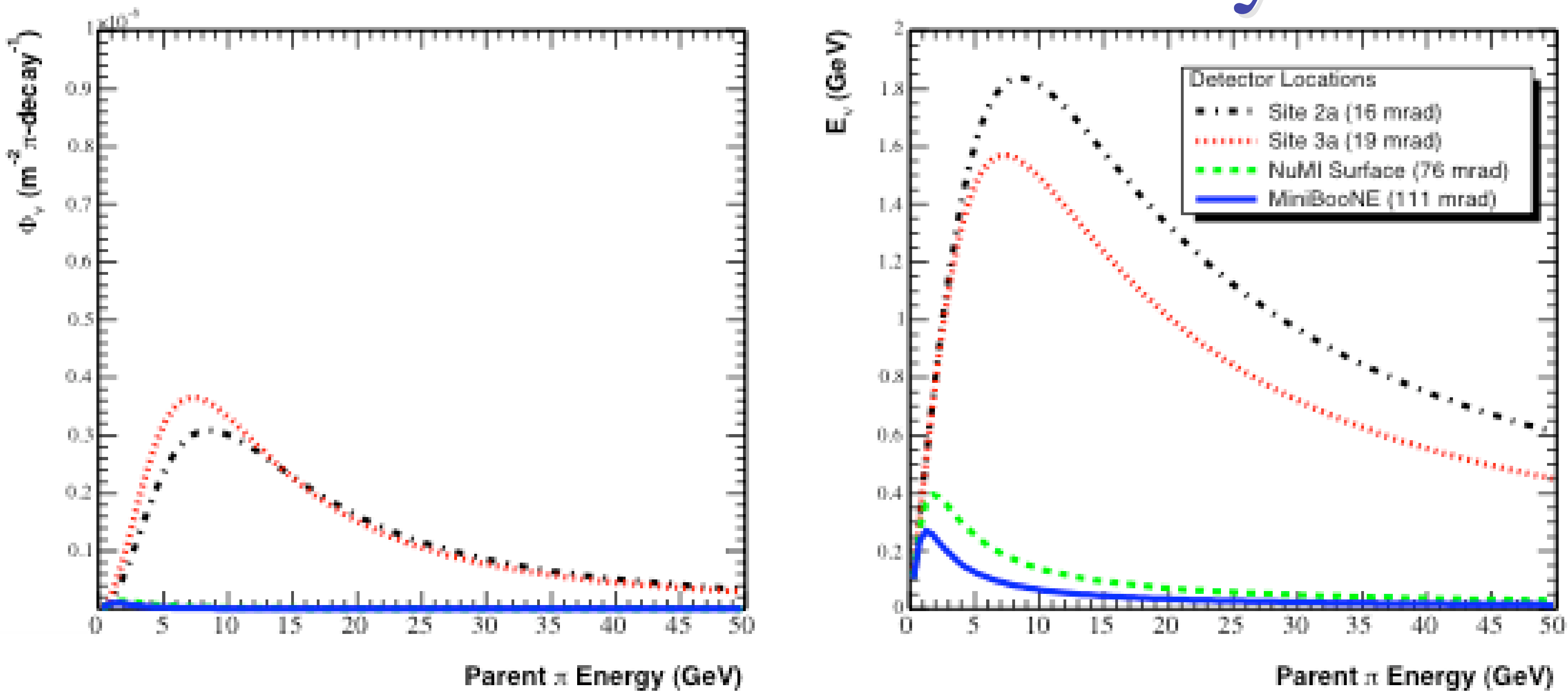
Type	***Cross Sec.***	***E<1 GeV***	***E>1 GeV***	***Role***
ν_μ	CCQE	~5%(SciBooNE)	5% (MINERvA)	$\nu_\mu(\nu_e)$ signal
ν_μ	CC1π^+(res)	~5%	5%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	CC1π^+(coh)	~10%	5%	$\nu_\mu(\nu_e)$ BG(E)
ν_μ	NC1π^0(res)	~10%	10%	ν_e BG(#,E)
ν_μ	NC1π^0(coh)	~15%	20%	ν_e BG(#,E)
$\bar{\nu}_\mu$	CCQE	~10%	?	$\bar{\nu}_\mu$ ($\bar{\nu}_e$) signal
$\bar{\nu}_\mu$	CC1π^-(res)	~10%	?	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	CC1π^-(coh)	~10%	?	$\bar{\nu}_\mu(\bar{\nu}_e)$ BG(E)
$\bar{\nu}_\mu$	NC1π^0(res)	~15%	?	$\bar{\nu}_e$ BG (#,E)
$\bar{\nu}_\mu$	NC1π^0(coh)	~20%	?	$\bar{\nu}_e$ BG (#,E)

NuMI Off-Axis Locations



- Several locations available for (small) detector installation in NuMI off axis tunnel
- We studied fluxes at two such locations:
  - 2A - 16 mrad off axis
  - 3A - 19 mrad off-axis
- Thanks:
  - Mark Messier for locations in beam coordinate system
  - Debbie Harris, from whose slides we got this figure

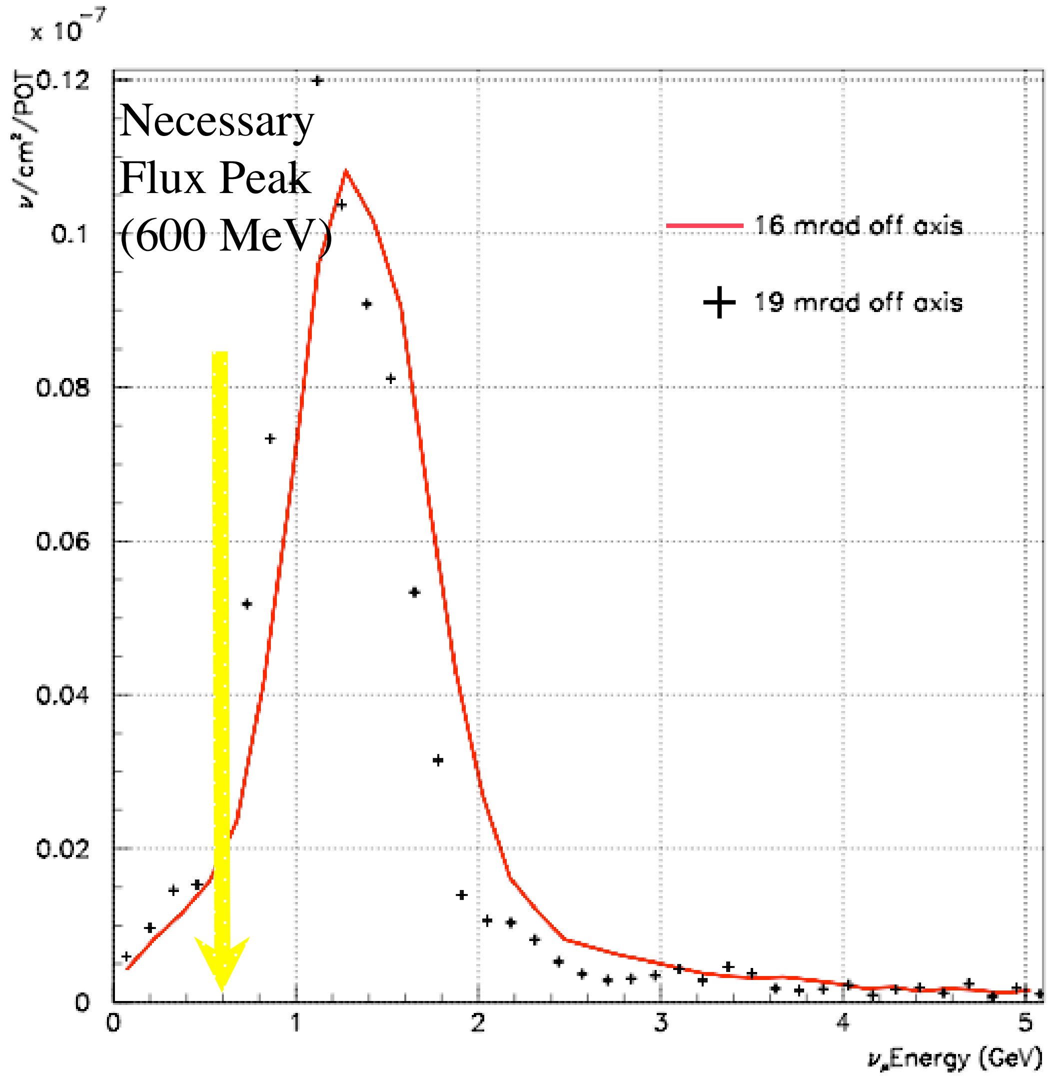
NuMI Off-Axis Study



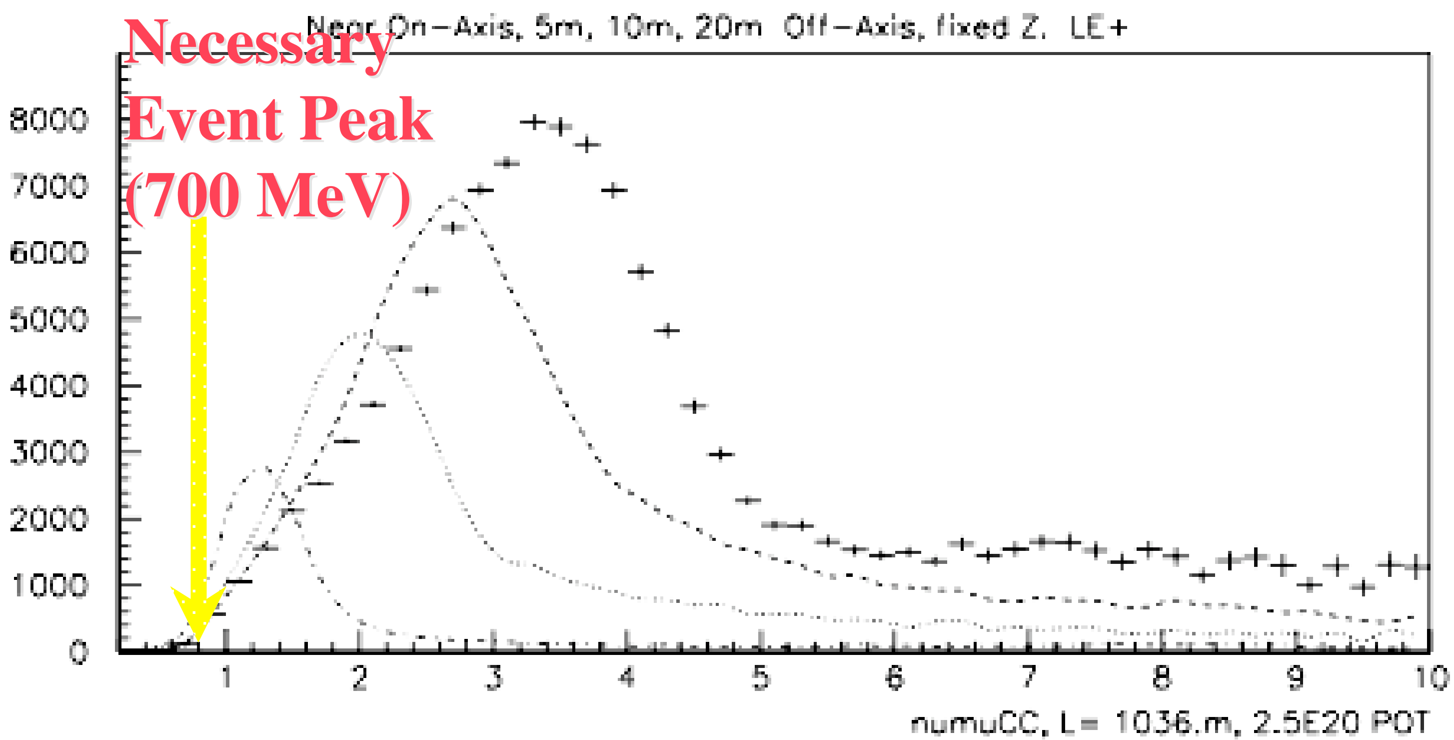
- Use "Off-Axis Formula" for π decay in flight
- E_π^{peak} = ~8.8 GeV (16mrad), ~7.5 GeV(19 mrad)
  E_ν^{peak} = ~1.85 GeV (16mrad), ~1.55 GeV(19mrad)
- Compare to MiniBooNE and MINOS surface hall

NuMI Off-Axis Fluxes

- gnumi neutrino beam Monte Carlo
- Flux prediction for two off-axis locations
  - Pion decays in flight
- Unsuitable for our physics goals
  - Peak energy too high
  - Significant HE tail makes formidabel BGs for NC events



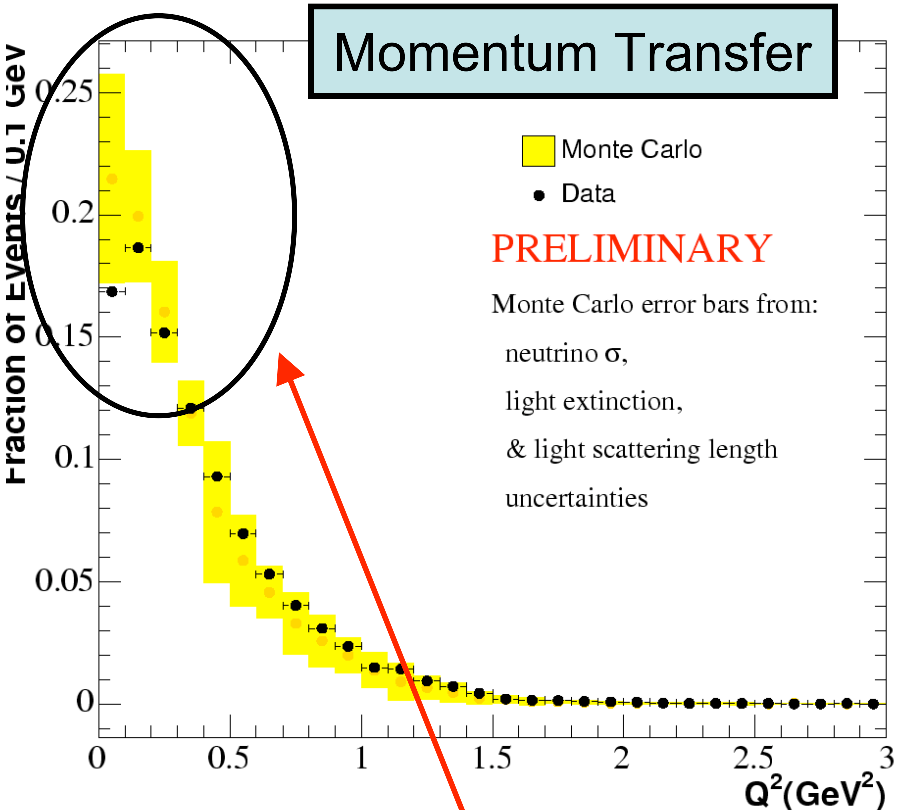
NuMI Off-Axis Events

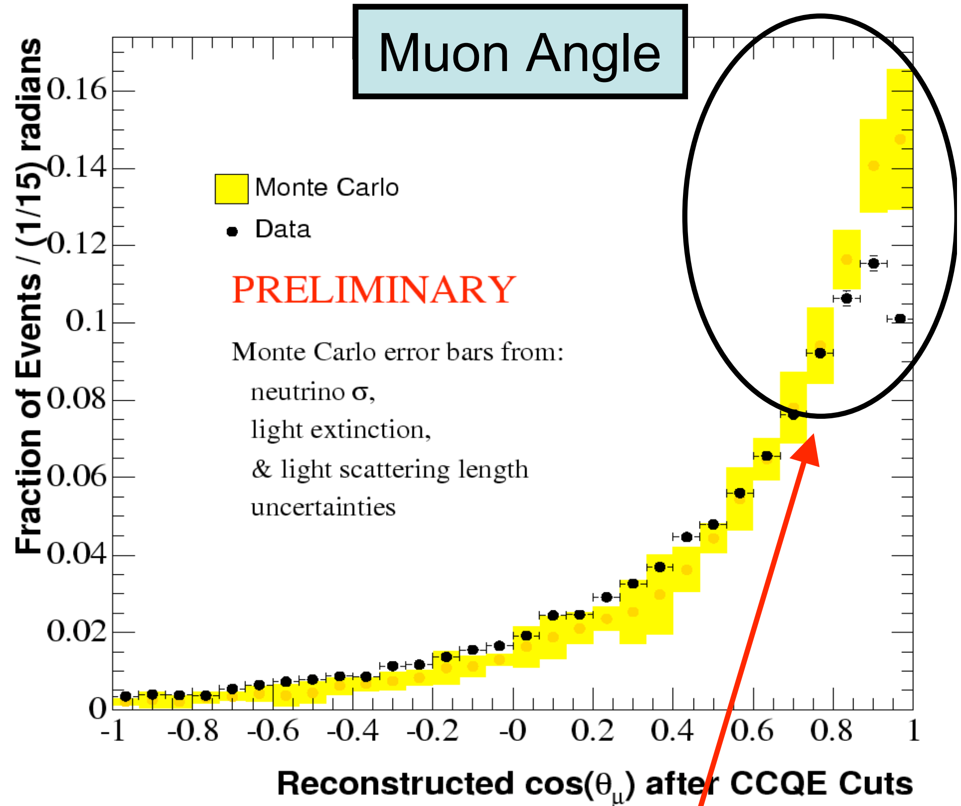


from MINERνA proposal

- Event Distributions at various off axis locations in NuMI
  - On-axis, 5 mrad, 10 mrad, 20 mrad
- Confirms previous plot: NuMI off-axis locations are not suited to SciBooNE physics goals
- Availability of SciBar is dependent on utility for T2K

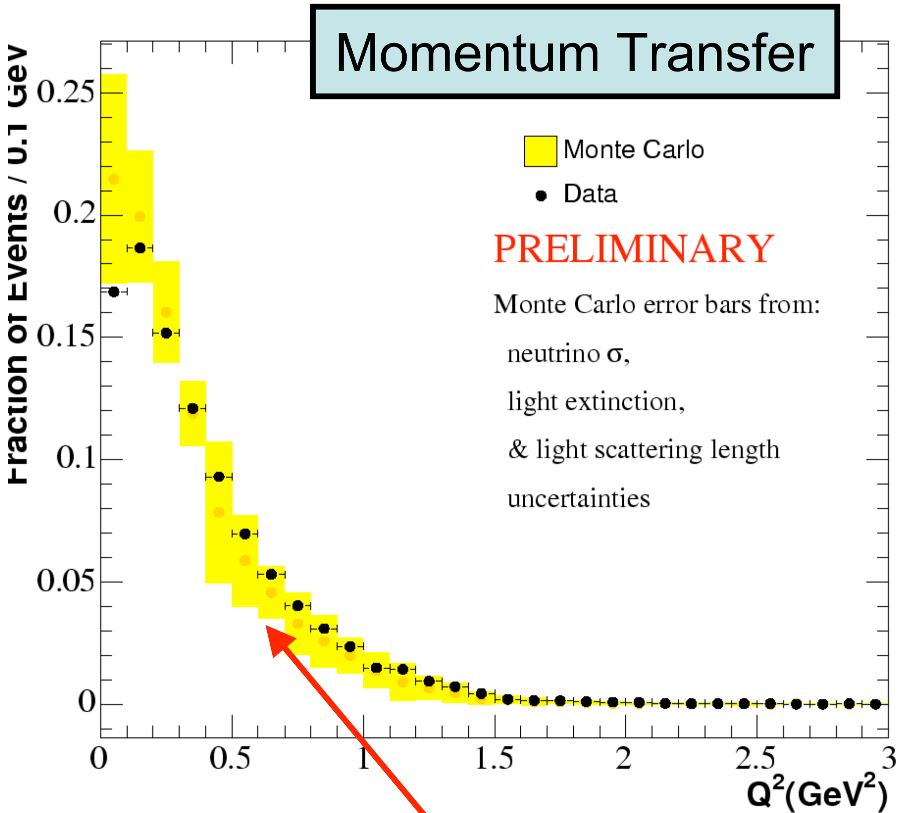
MiniBooNE CCQE σ on CH_2

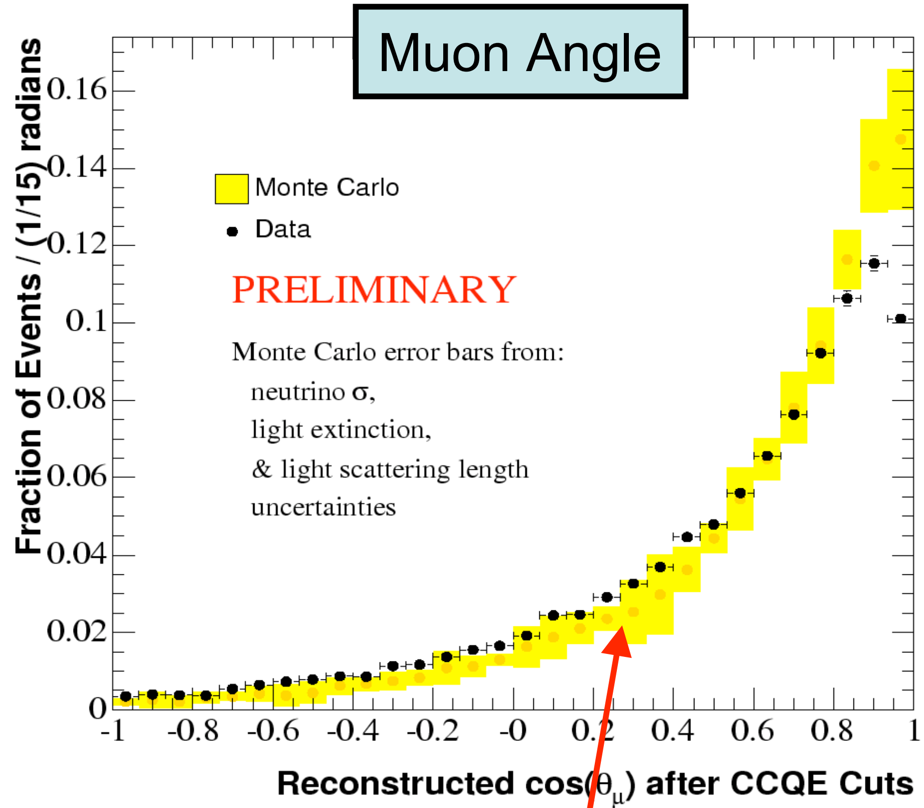




- Deficit of events at low Q2
  - Corresponds to forward angle muons (good angular resolution)
- Indicates some new physics?

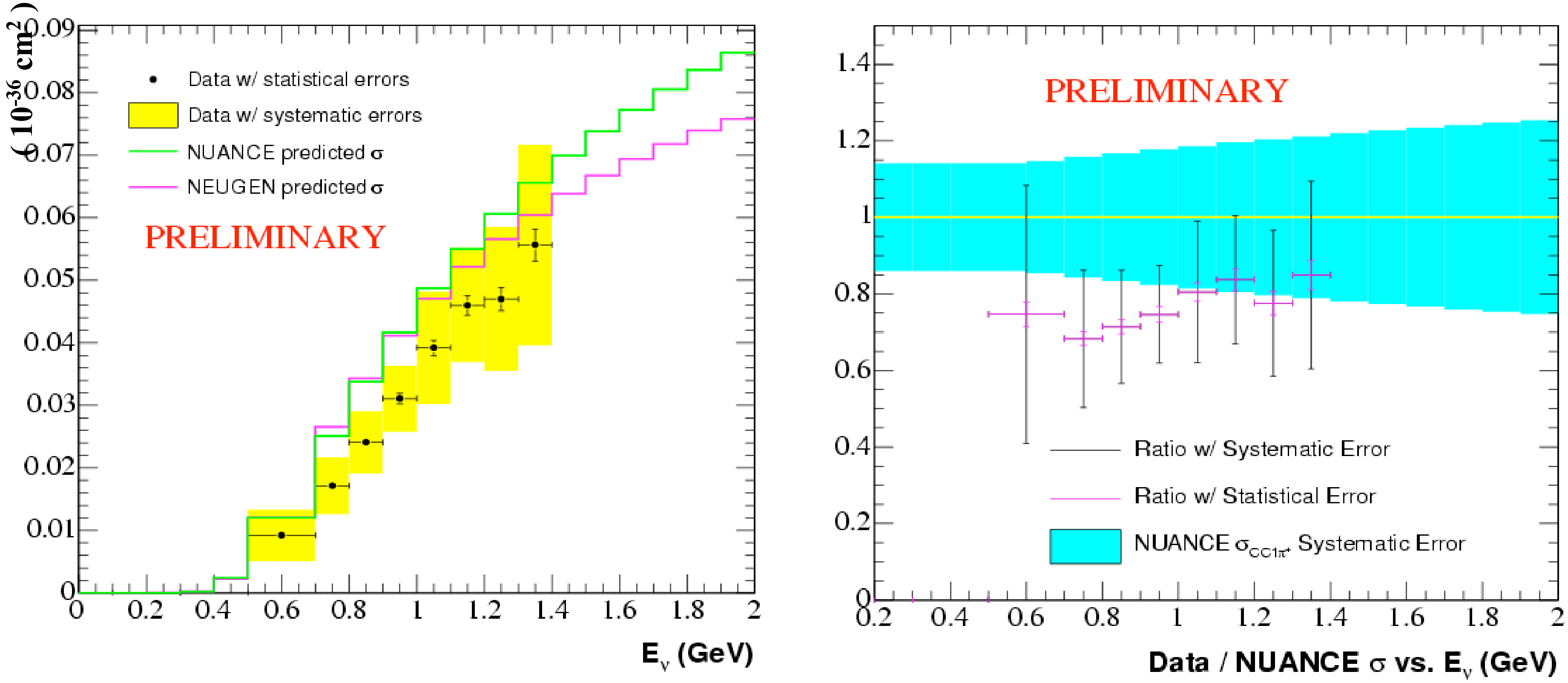
MiniBooNE CCQE σ on CH_2





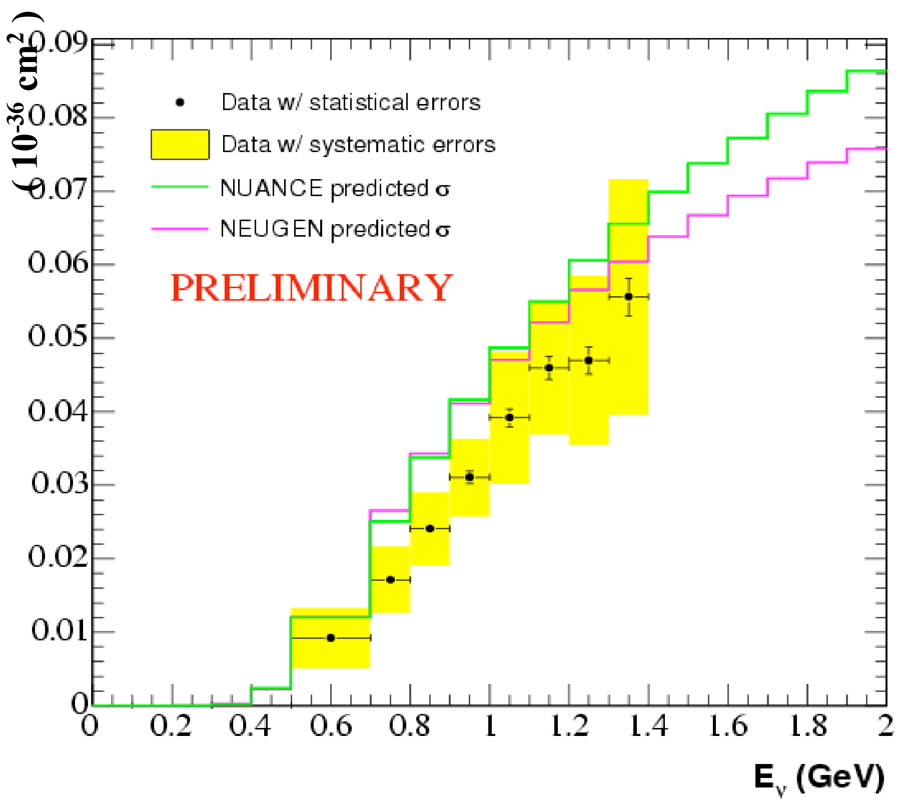
- Shape at higher Q^2 disagrees
  - Corresponds to large angle muons (good angular resolution)
- Indicates higher M_A?

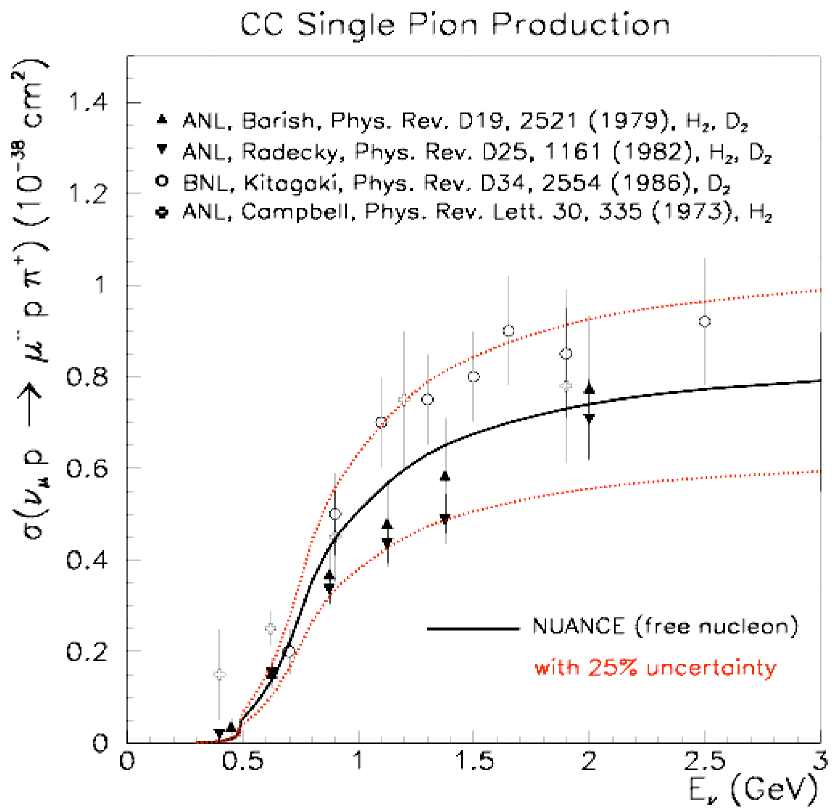
MiniBooNE CC1π^+ σ on CH_2



- systematic errors due to ν cross sections (~15%),
- photon atten. and scatt. lengths in oil (~20%),
- energy scale (~10%)
- MiniBooNE result lower than NUANCE prediction
  - More consistent with ANL result than BNL result

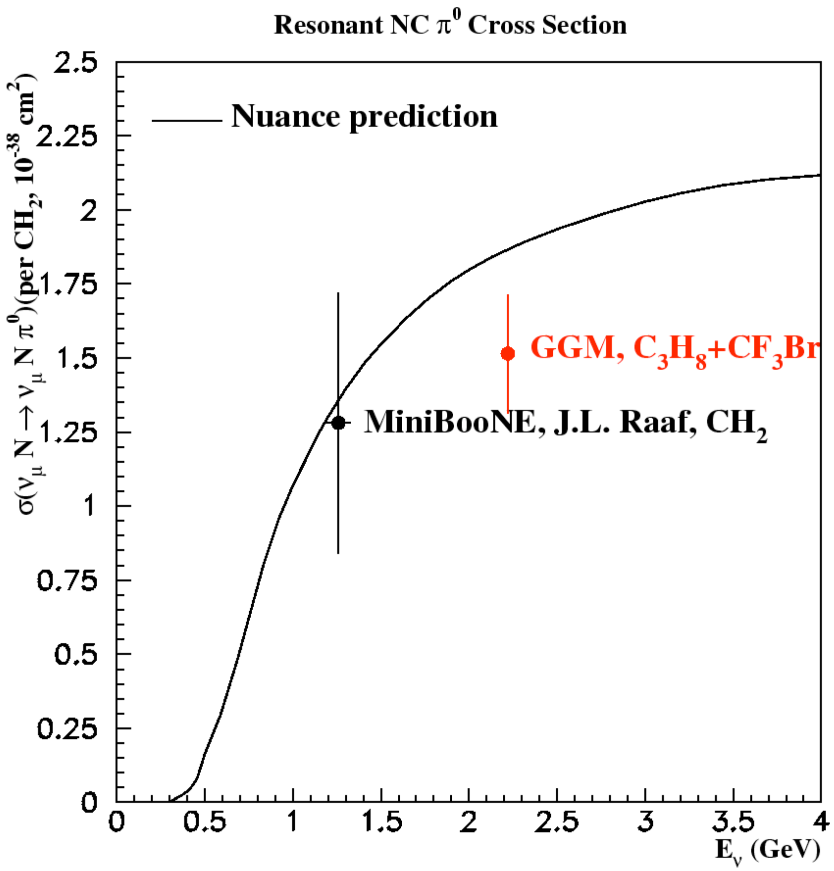
MiniBooNE CC1π^+ σ on CH_2

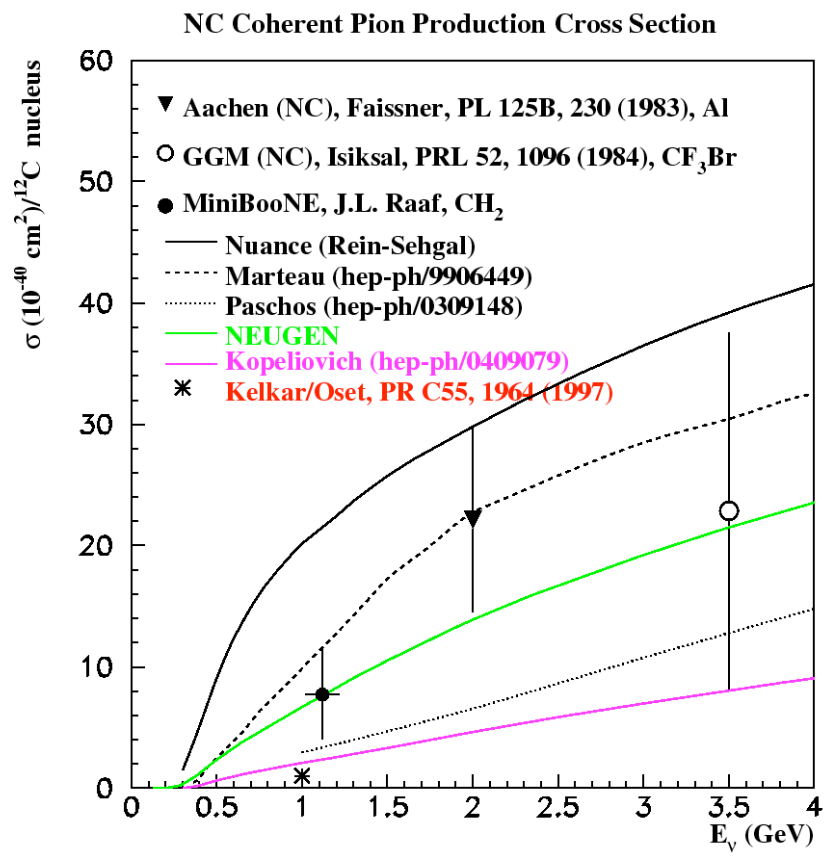




- systematic errors due to ν cross sections (~15%),
- photon atten. and scatt. lengths in oil (~20%),
- energy scale (~10%)
- MiniBooNE result lower than Monte Carlo predictions
    - More consistent with ANL result than BNL result

MiniBooNE NC1π^0 σ on CH_2

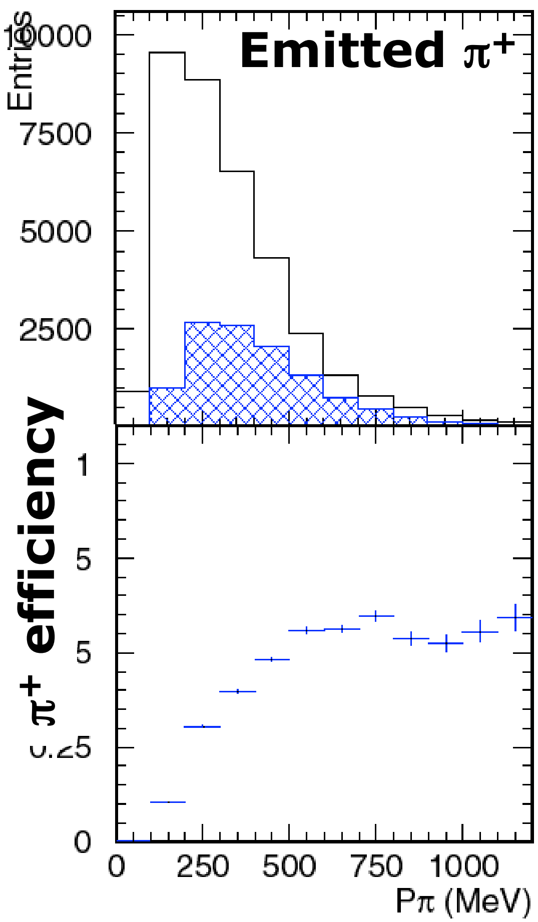




- systematic errors:
  - cross section uncertainties (~15%, 20%)
  - energy scale (5%)
- MiniBooNE coherent fraction well below Rein-Sehgal and Marteau

SciBooNE CC-1π^+ measurement

π^+ detection efficiency as a function of $P\pi^+$



CC-1π^+ signature: 2-track, both are MIP-like

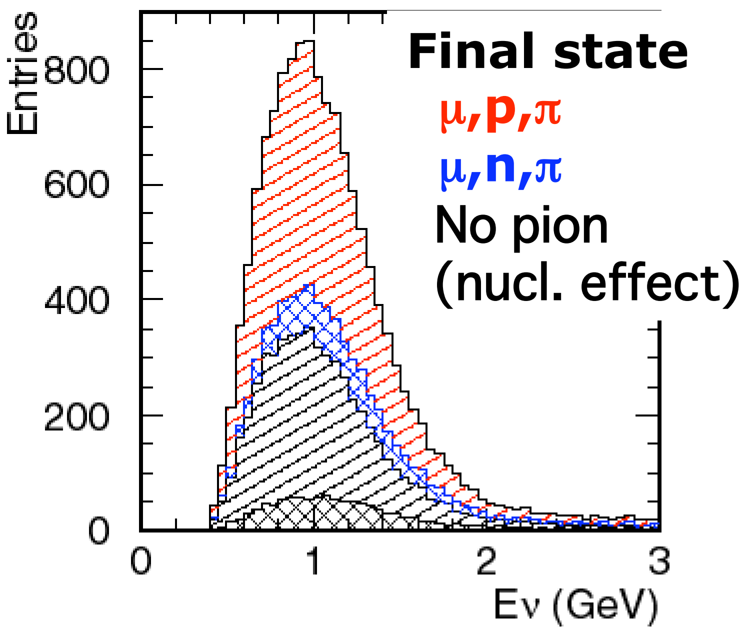
Selection criteria	#(CC-1π^+) [events]	Purity	Efficiency
Generated in FV	13,892	-------	100%
CC inclusive sample (SciBar+EC+MRD)	8,977	24.1%	64.6%
# of tracks =2	2,705	32.6%	19.5%
2^{nd} track = MIP-like	1,355	46.8%	9.8%

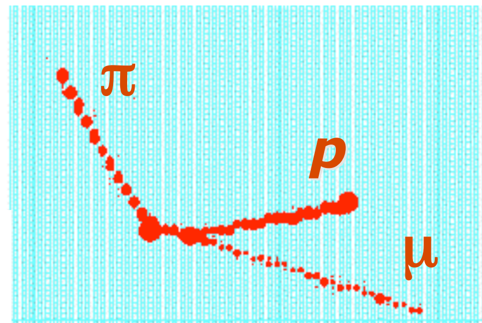
Additional vertex activity can separate $\nu+p \rightarrow \mu+p+\pi^+$ from $\nu+n \rightarrow \mu+n+\pi^+$

Statistics will allow a 5% measurement

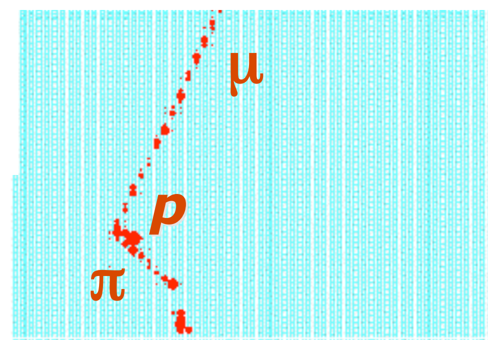
SciBooNE CC-1π^+ measurement

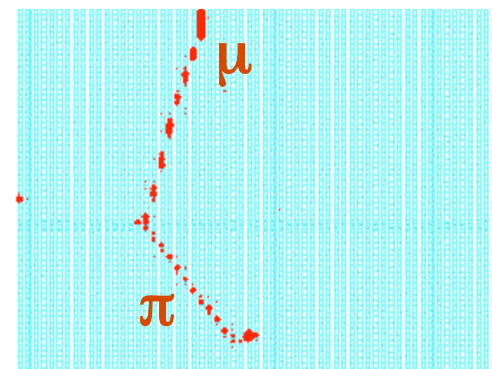
Eν distribution for CC-1$\pi^{\pm}$

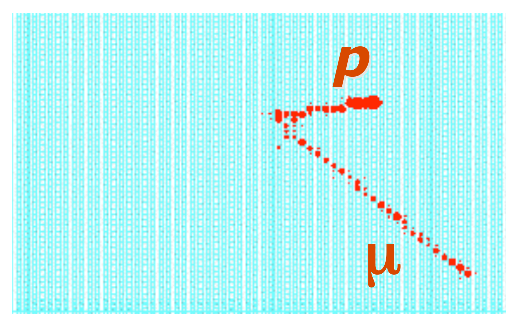




SciBar has the ability to separate the final state





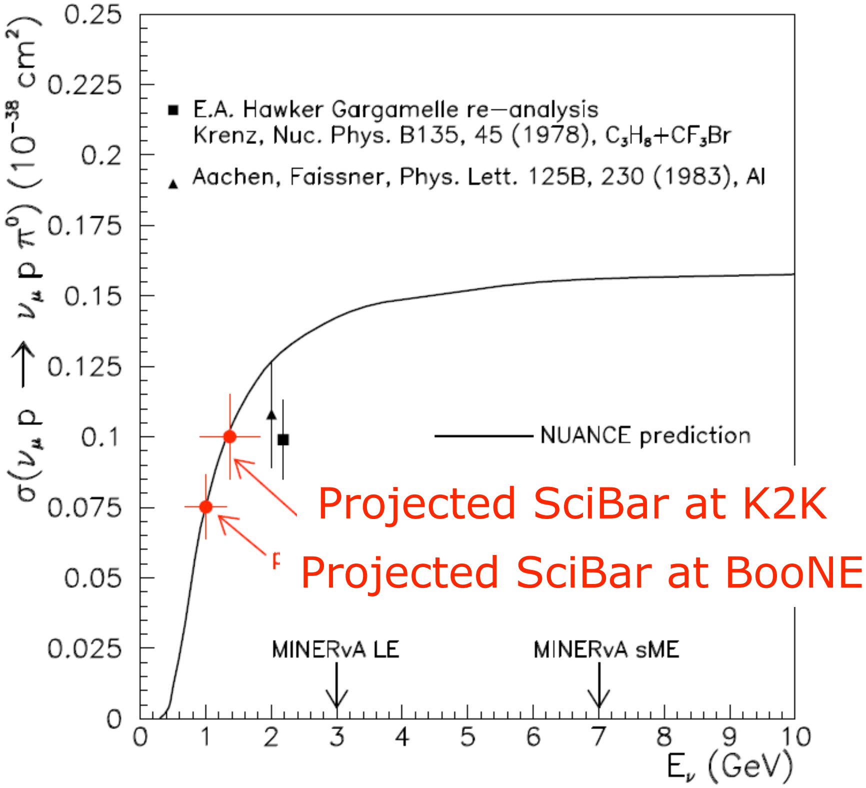


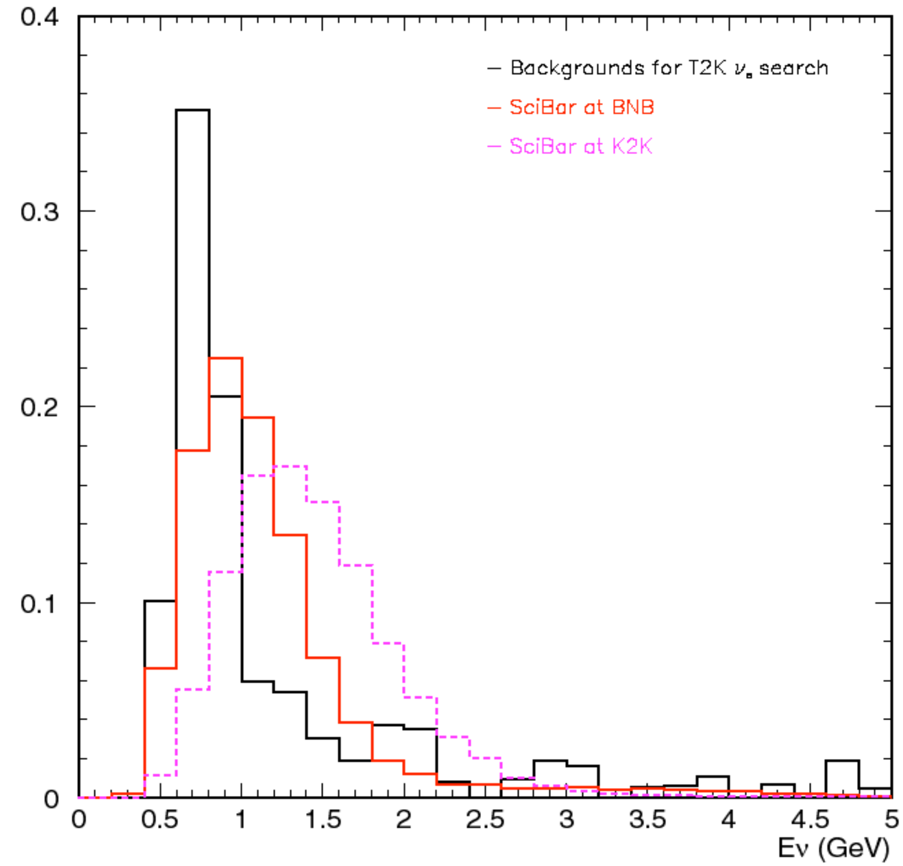
⇨ **Sensitive to the nuclear effect**

Clear event-by-event final-state tagging!

SciBooNE NC-1π^0 measurement

$\sigma(\nu+p \rightarrow \nu+p+\pi^0)$



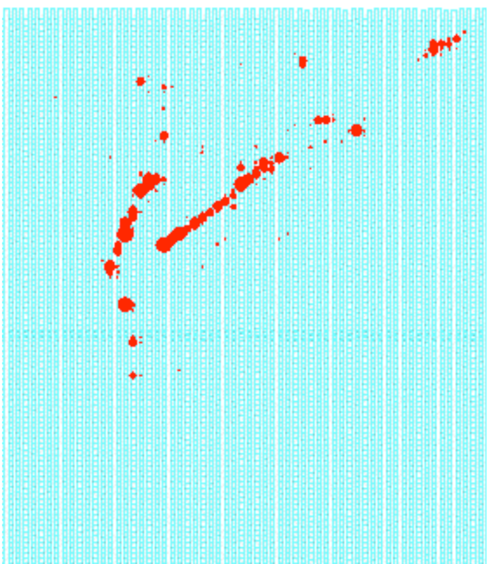


10% measurement

Map out energy dependence at point where cross section turns over, crucial for T2K NC1π^0 BGs

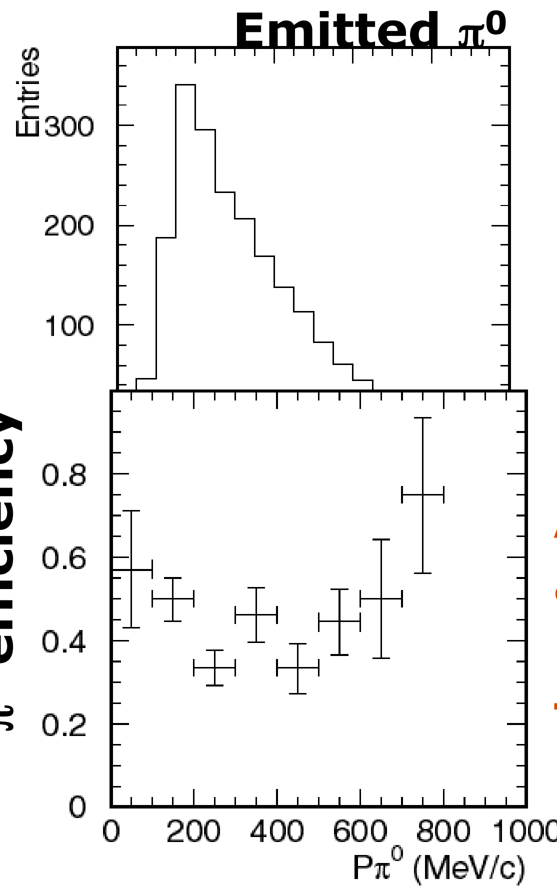
SciBooNE NC-1π^0 measurement

NC-1π^0 event display



π^0s are detected as two shower-like tracks in SciBar

π^0 detection efficiency as a function of Pπ^0

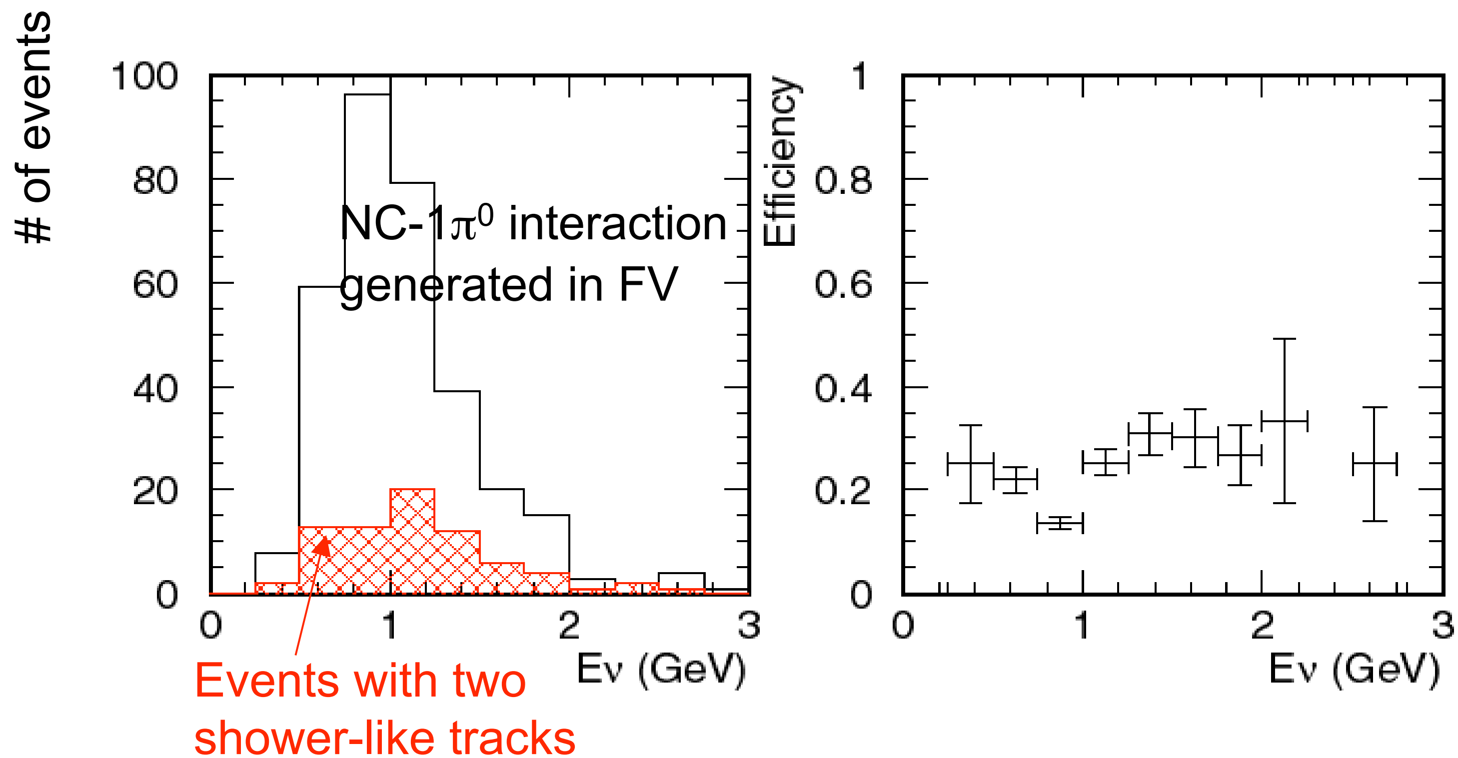


- Good efficiency for high-momentum π^0
- Reconstructed π^0 ~800events

Additional vertex activity can separate
$\nu+p \rightarrow \nu+p+\pi^0$
from
$\nu+n \rightarrow \nu+n+\pi^0$

SciBooNE NC-1π^0 efficiency as a function of neutrino energy

Estimated by eye-scan of event display



NOTE: black histogram includes the events that π^0 is not emitted due to nuclear effect

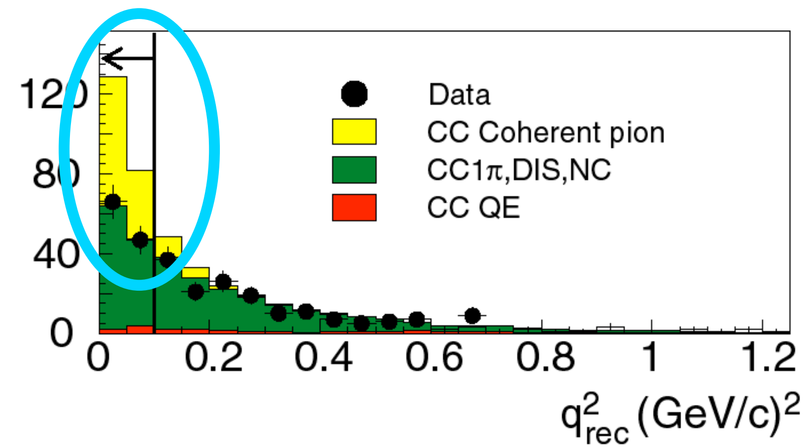
Why do the neutrino cross section help future experiments, like T2K?

- Observables $\propto$ Flux(Φ) $\times$ $\sigma(E_\nu)$ $\times$ efficiency (ε)

	Φ	$\sigma(E_\nu)$	ε	E_ν(GeV)
K2K-ND	(HARP)	Some results	Well-understood	1.3
MiniBooNE	(HARP)	Under Progress	Under calibration & tuning	0.7
SciBar@BNB	(HARP)	Will be [illegible]	Well-understood	0.7
T2K-ND280			need some time	0.7
MINERνA	(MIPP)	-----	??	2~5?

CC-coherent π measurement

- CC-coherent π: **ν+A→μ+A+π**
- Physics motivation
  - SciBar observed no CC-coherent π production in the K2K beam (hep-ex/0506008)



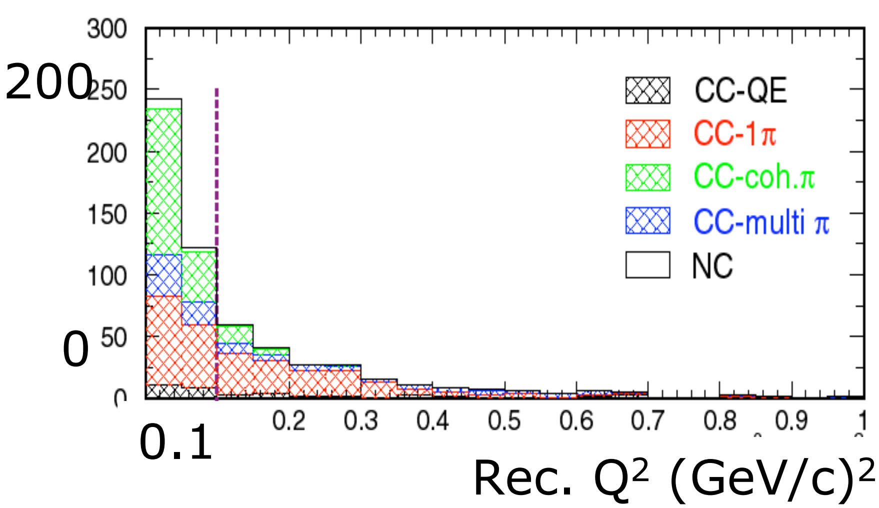
$$\frac{\sigma(CC-Coh\,\pi)}{\sigma(\nu_\mu CC)} < 0.60\times10^{-2} @ 90\%CL$$

  - It will be a good check by using both neutrino and anti-neutrino beam

CC-coherent π measurement (cont'd)

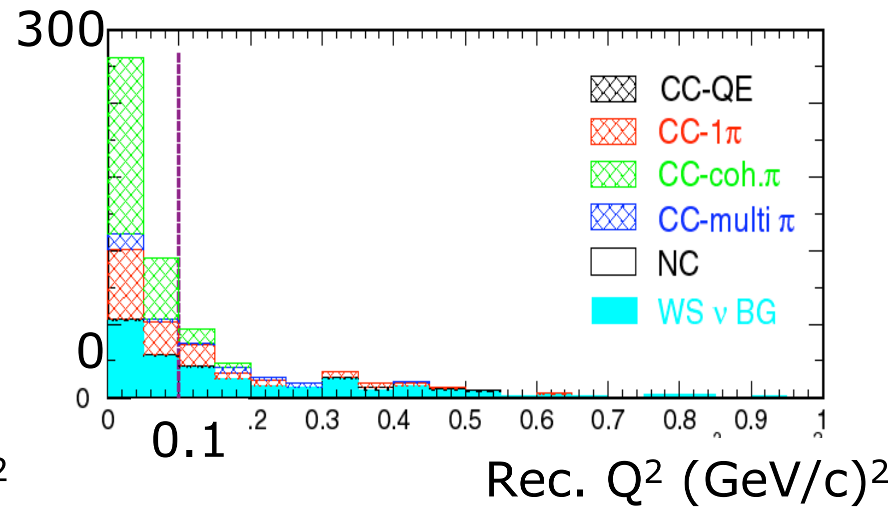
Rec. Q^2 distribution of final sample

Neutrino Run(0.5×10^{20}POT)



#(coherent π)~160events
Efficiency = 0.11
Purity = 0.44

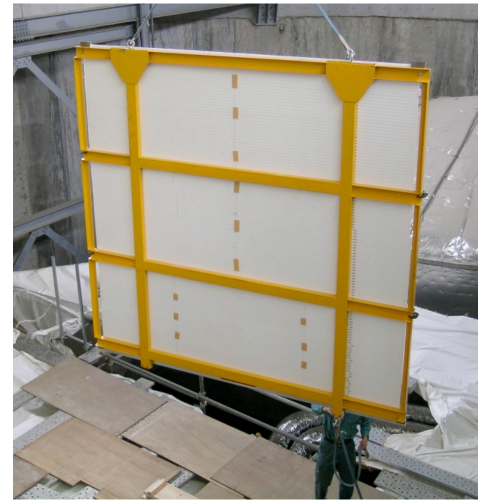
Anti-neutrino Run(1.5×10^{20}POT)

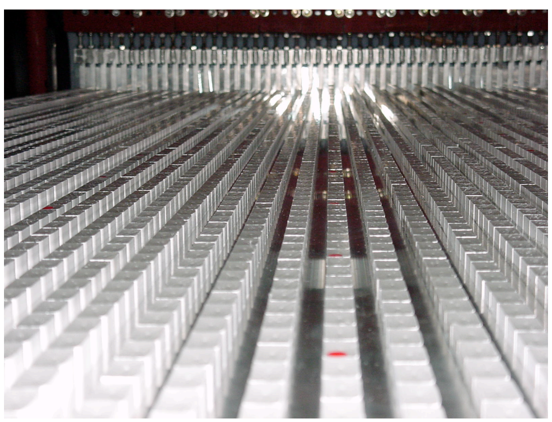


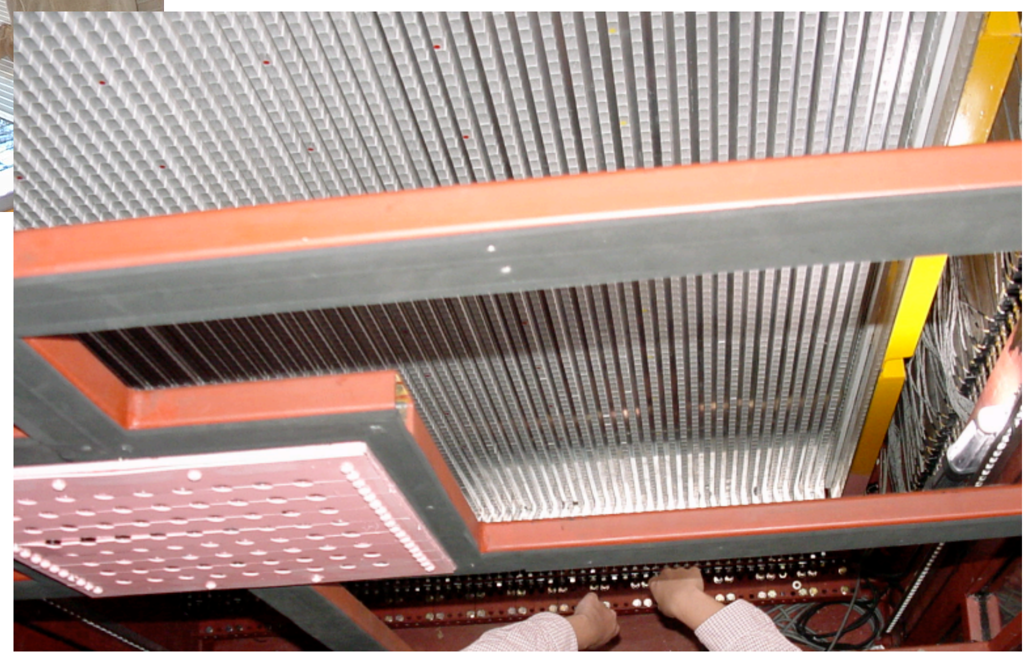
#(coherent π)~240events
Efficiency = 0.11
Purity = 0.49

We can measure in both neutrino and anti-neutrino beam

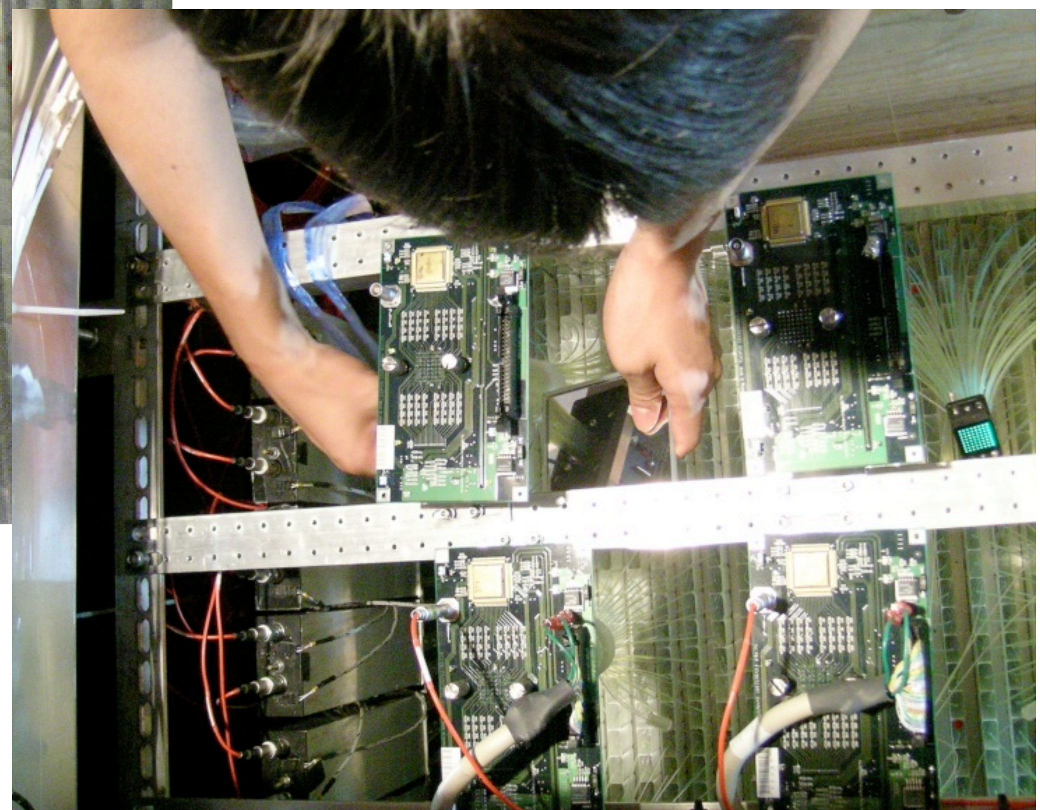
SciBar Installation (1)



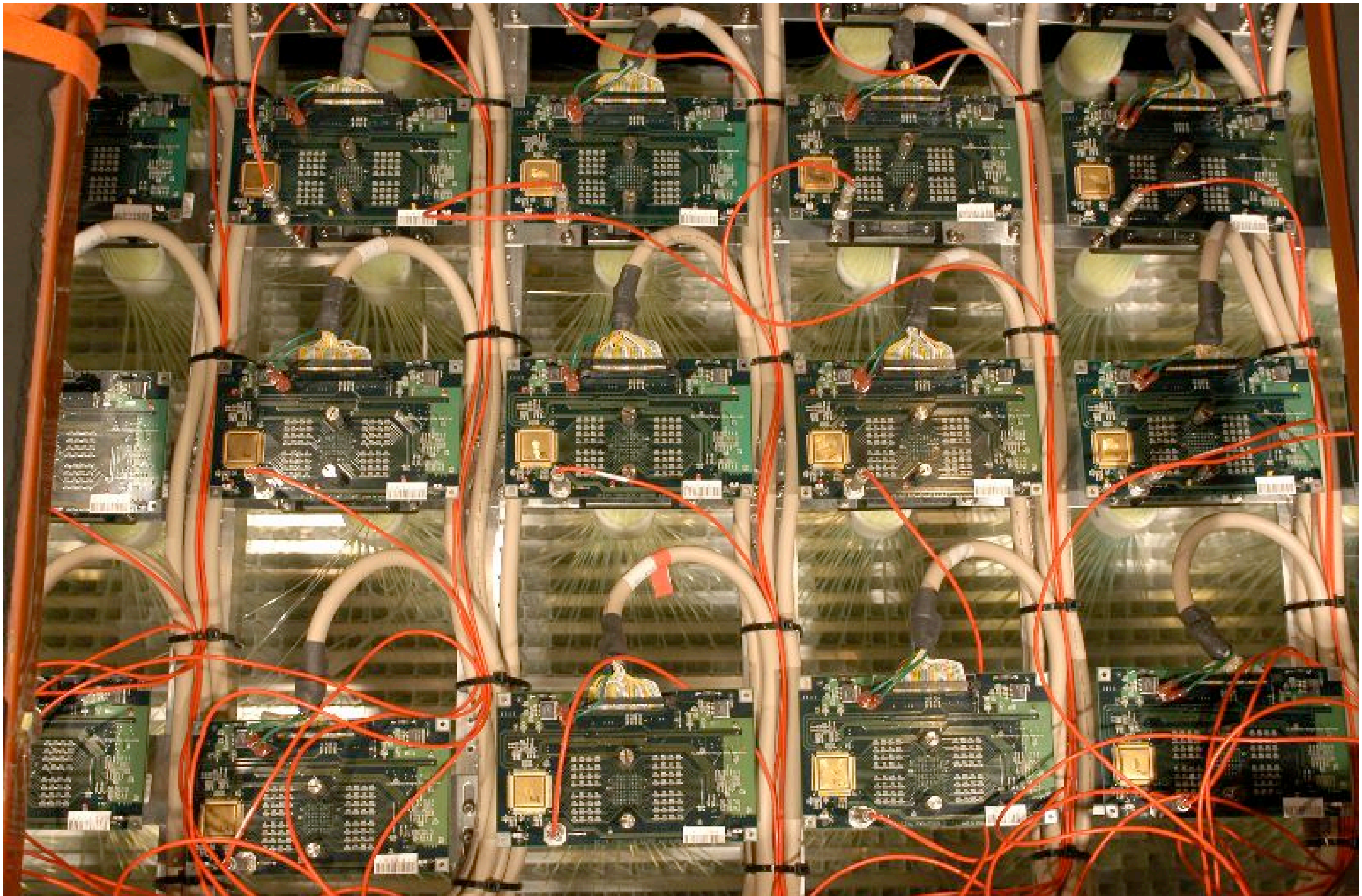




SciBar Installation (2)



SciBar Installation – complete !

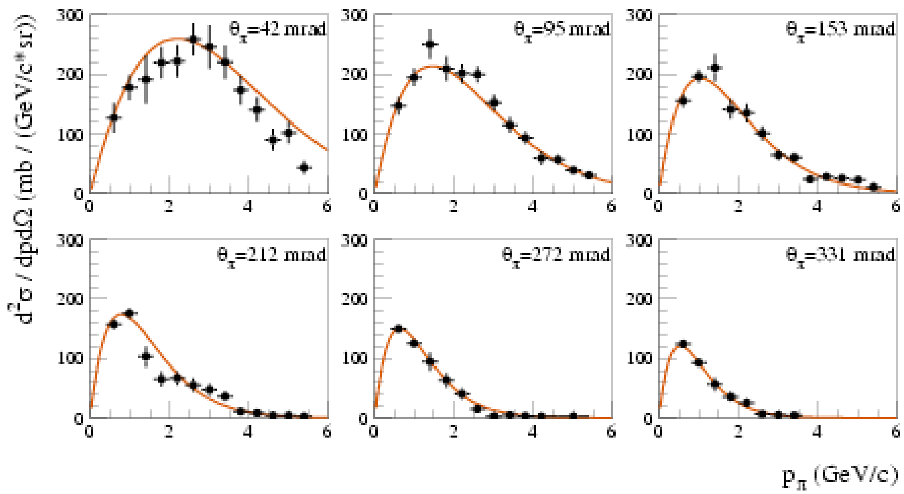


Calculating the BNB Φ_ν

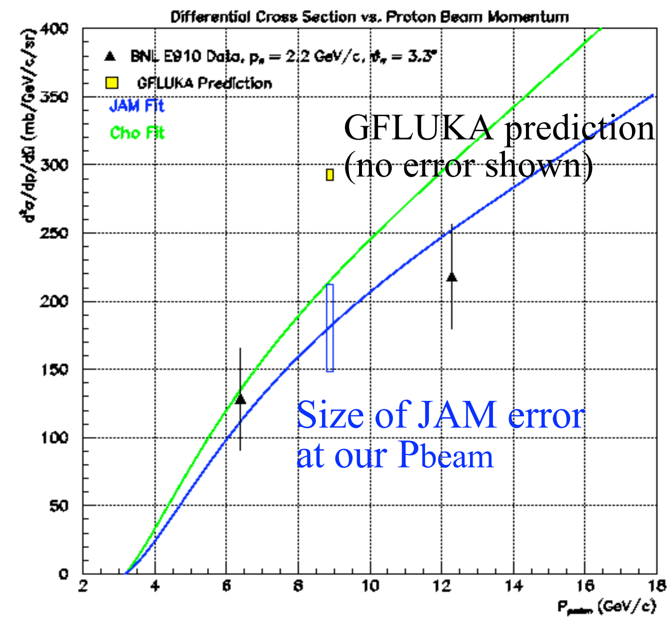
primary p Be $\rightarrow \pi^+$ X interactions:

- Sanford-Wang parameterization fit to E910 hadron production data, 6 and 12 GeV

12.3 GeV/c E910 beryllium Data



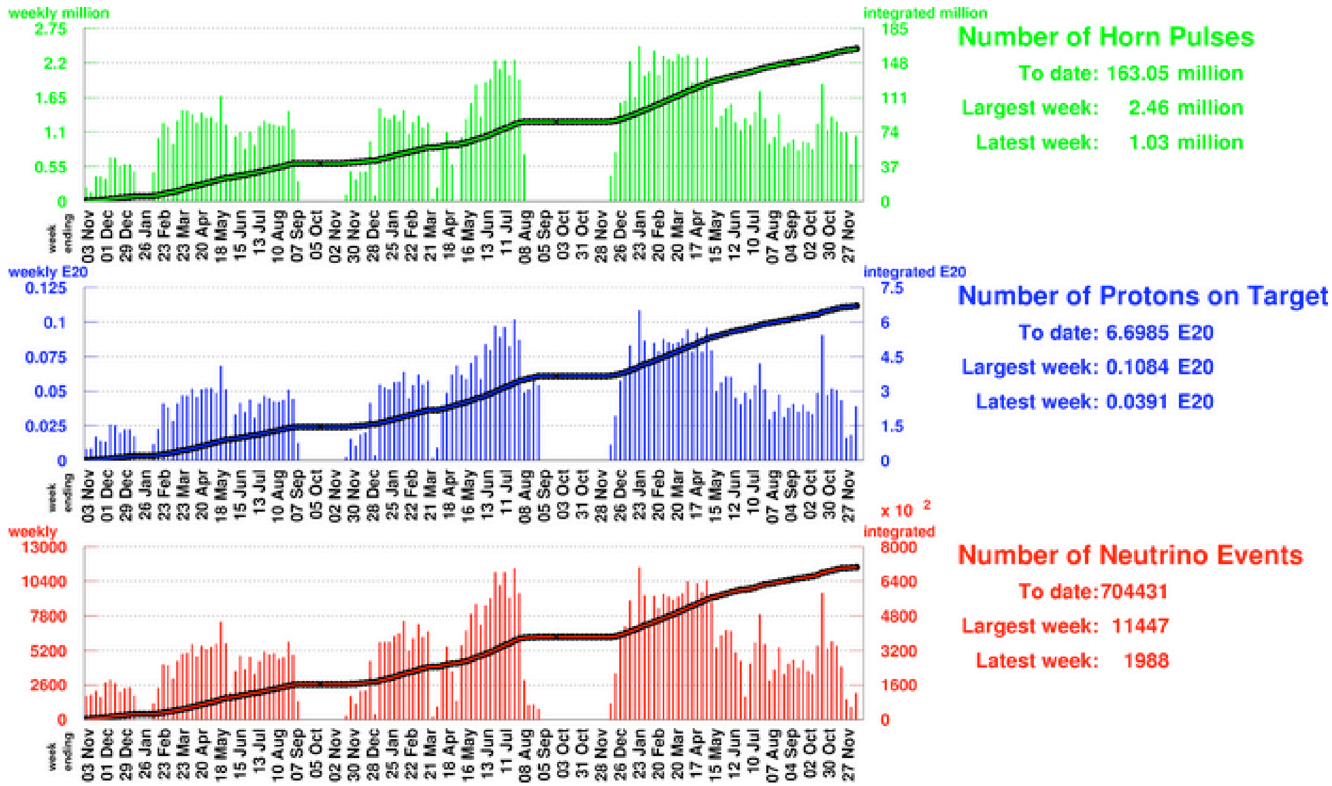
J.Link, Columbia



Y. Cho et al., Phys. Rev. **D4**, 1967 (1971)

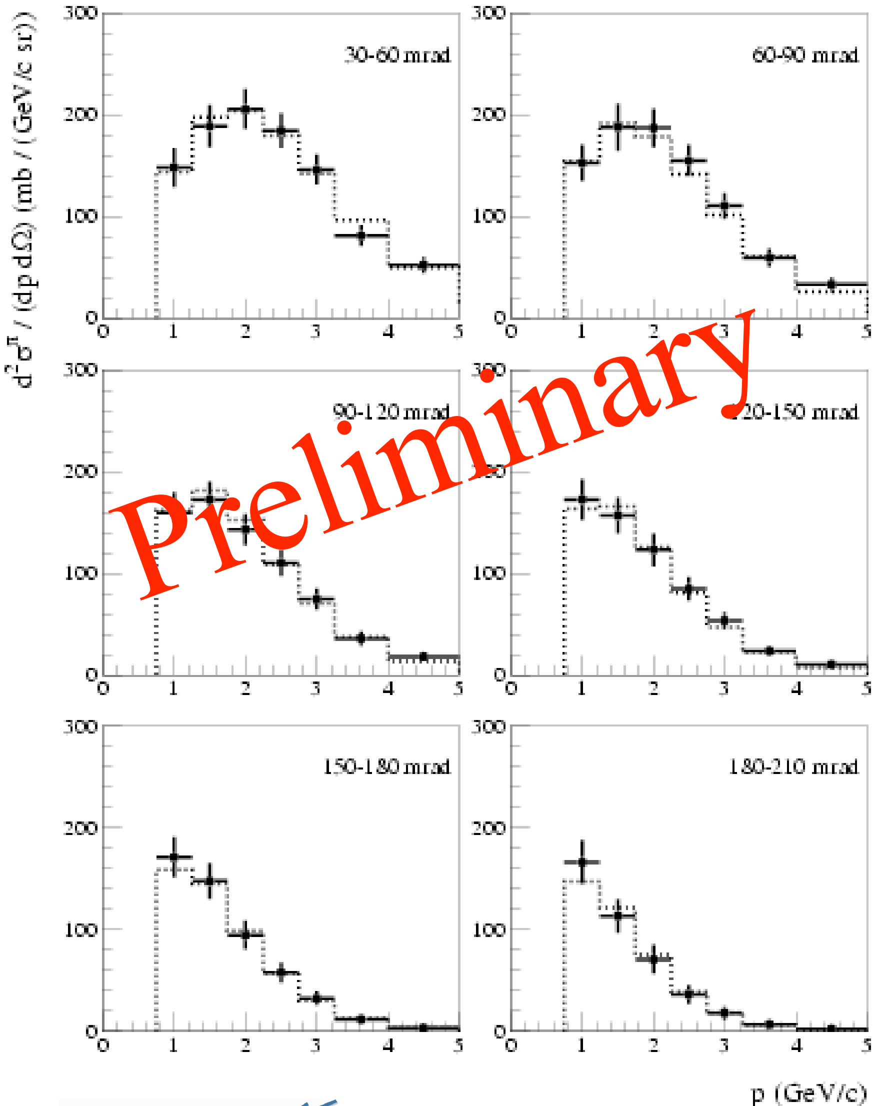
- Parametrization
  - allows extrapolation from various data sets (different p_{beam})
  - allows interpolation of cross section tables between existing experimental data
  - E910 publication in preparation
  - HARP will nail down production at 8 GeV with small errors (use E910 fit as cross check)

BNB Proton Delivery



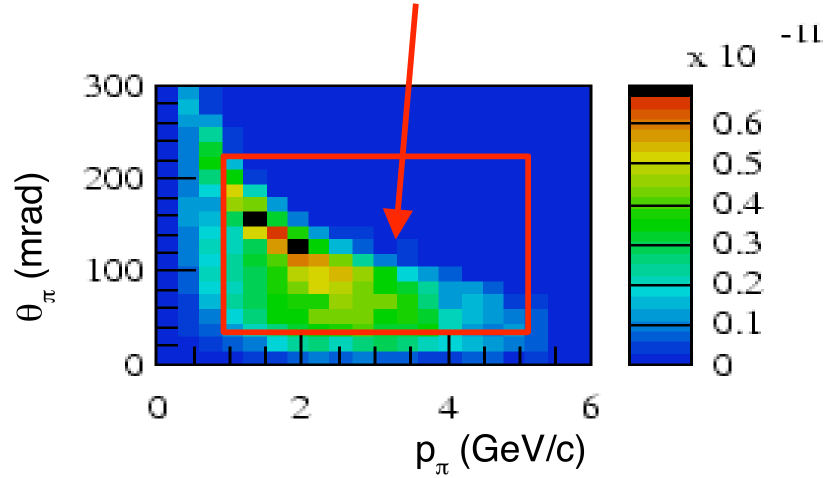
- Directorate recommends planning on 1-2E20 POT
- We assume 2E20 POT in a one year run
  - 0.5E20 POT in ν mode, 1.5E20 in $\bar{\nu}$ mode
  - This is consistent with FNAL Proton Plan

HARP Beryllium Thin Target Results



Preliminary double differential π^+ production cross sections from the Be 5% target are available

$0.75 < p_\pi < 5$ GeV/c
$30 < \theta_\pi < 210$ mrad



Momentum and Angular distribution of pions decaying to neutrinos that pass through the MB detector.

Error Evaluation

For HARP p Al $\rightarrow \pi^+$ X

- Thorough systematics error evaluation performed, to quantify errors on both:

- $d^2\sigma^\pi/(dpd\Omega)\ (p,\theta)$

Typical error: **8.7%**

- $\sigma^\pi(0.75<p<6.5\,GeV/c, 30<\theta<210\,mrad)$

Error on total cross-section: **4.7%**

Error Source	δ_{diff} (%)	δ_{int} (%)
Overall normalization	4.0	4.0
Momentum scale	3.6	0.3
Al target statistics	3.2	0.6
Acceptance correction	2.6	0.7
(π, p) PID	2.5	0.5
Empty target statistics	2.2	0.4
Electron PID	2.1	0.5
Momentum resolution (smearing)	1.3	1.6
Empty target normalization	1.2	1.1
Momentum resolution (model dep.)	1.0	1.1
Reconstruction efficiency	0.8	0.2
Kaon PID	0.3	0.1
Secondary interactions	0.2	0.1
PID probability cut	0.2	0.1
Total	8.7	4.7

Total: 8.7% 4.7%

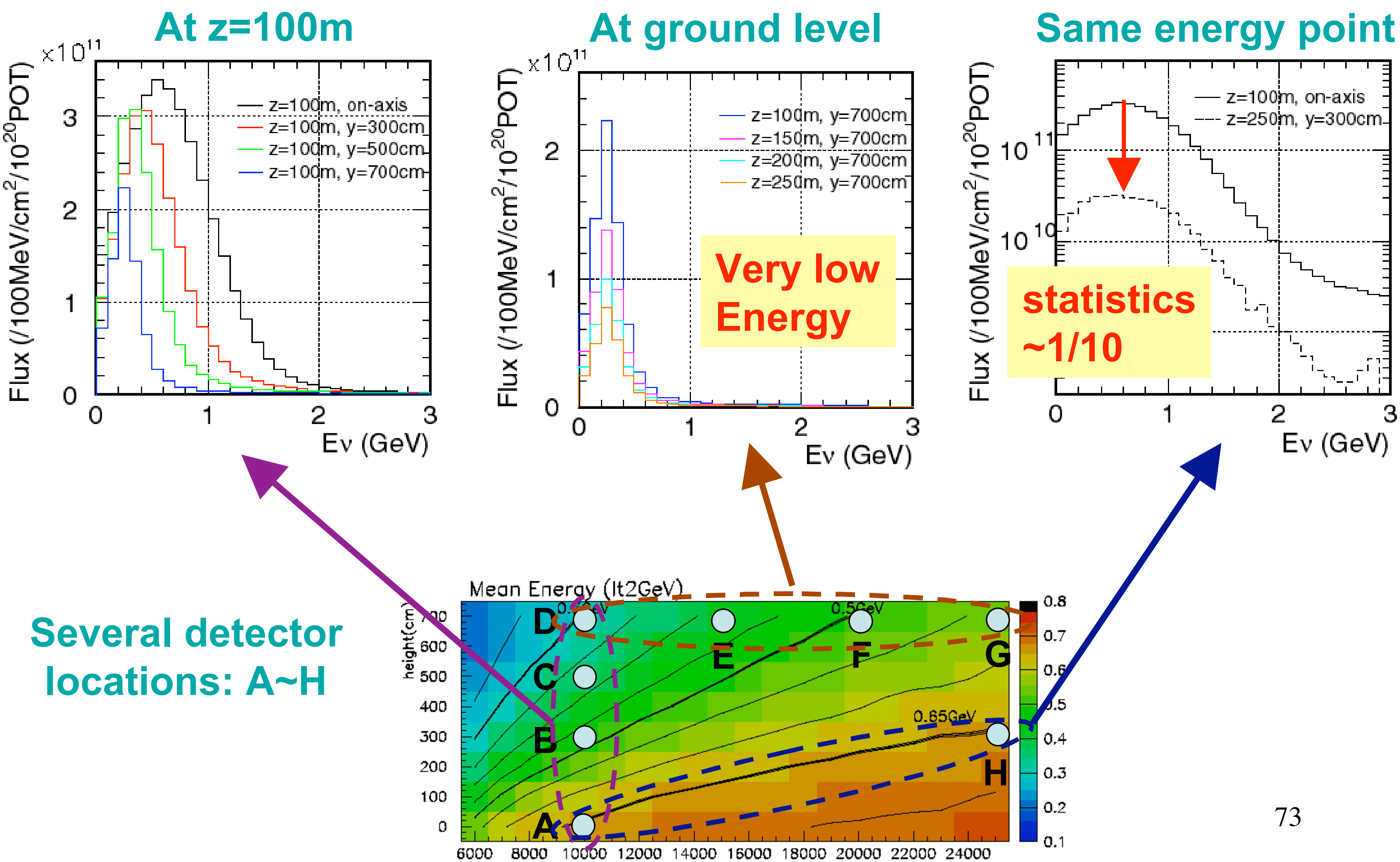
Dominant error contributions:

- Overall normalization
- Momentum scale
- Statistics

Similar systematics expected for Be

HARP data taken with thick targets will measure K fluxes

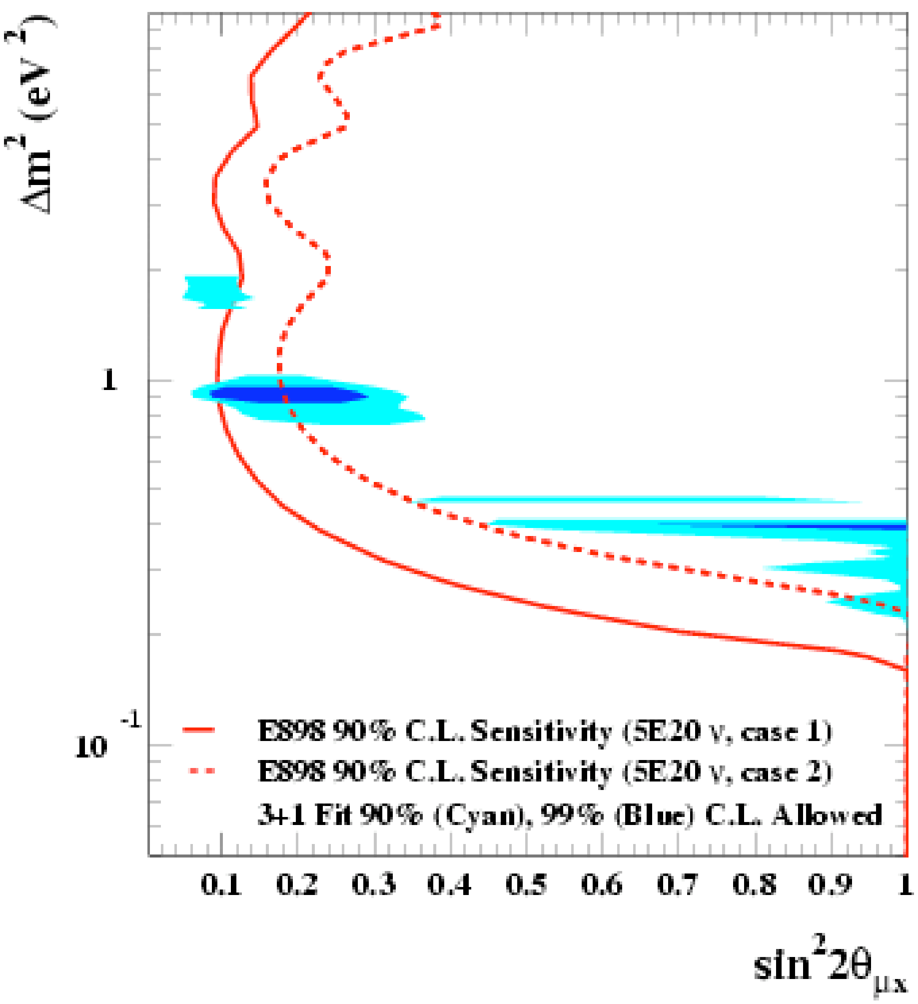
Expected neutrino flux



Several detector locations: A~H

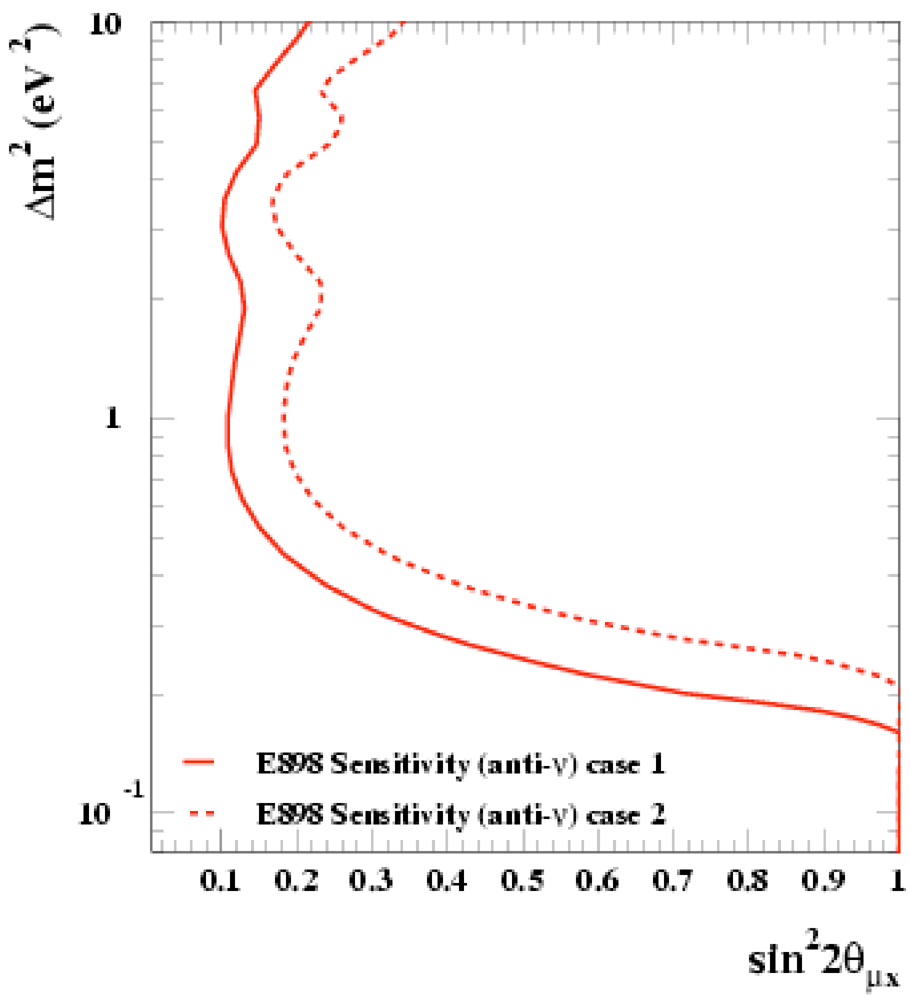
ν_μ Disappearance with MiniBooNE

- Sensitivity curves at right:
  - Case 2: 10% shape and 25% normalization uncertainties
  - Case 1: 5% shape and 10% normalization uncertainties
- Event spectrum shape is most important error source
  - Sensitivity mostly from spectral distortion characteristic of ν oscillations (low Δm2)
- SciBar measures un-oscillated event energy spectrum (Φ×σ)
  - Both detectors are carbon targets (same σ)
  - MiniBooNE flux acceptance w/in SciBooNE flux acceptance



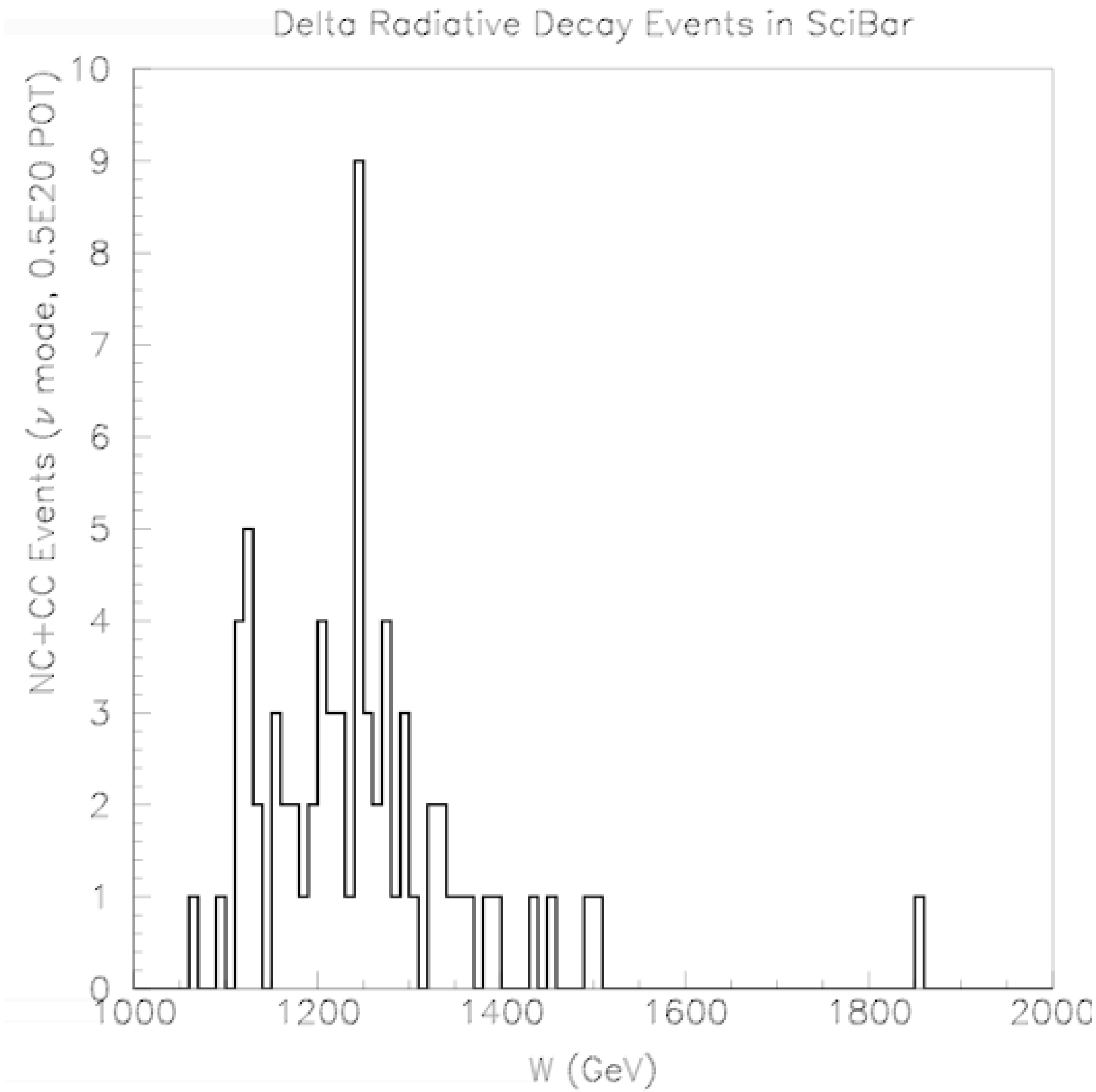
$\bar{\nu}_\mu$ Disappearance with MiniBooNE

- Need to know spectrum of WS BGs for $\bar{\nu}_\mu$ disappearance
  - Must extract energy spectrum of $\bar{\nu}_\mu$ events
- MB: 15% uncertainty on WS BG in 4 bins (0-1.5 Gev)
- SB: 7.5% statistical errors in WS (2 track) sample in 4 bins (0-1.5 GeV)
- Shown at right is the $\bar{\nu}_\mu$ disappearance sensitivity:
  - 5% shape and 10% normalization uncertainties
  - 10% shape and 25% normalization



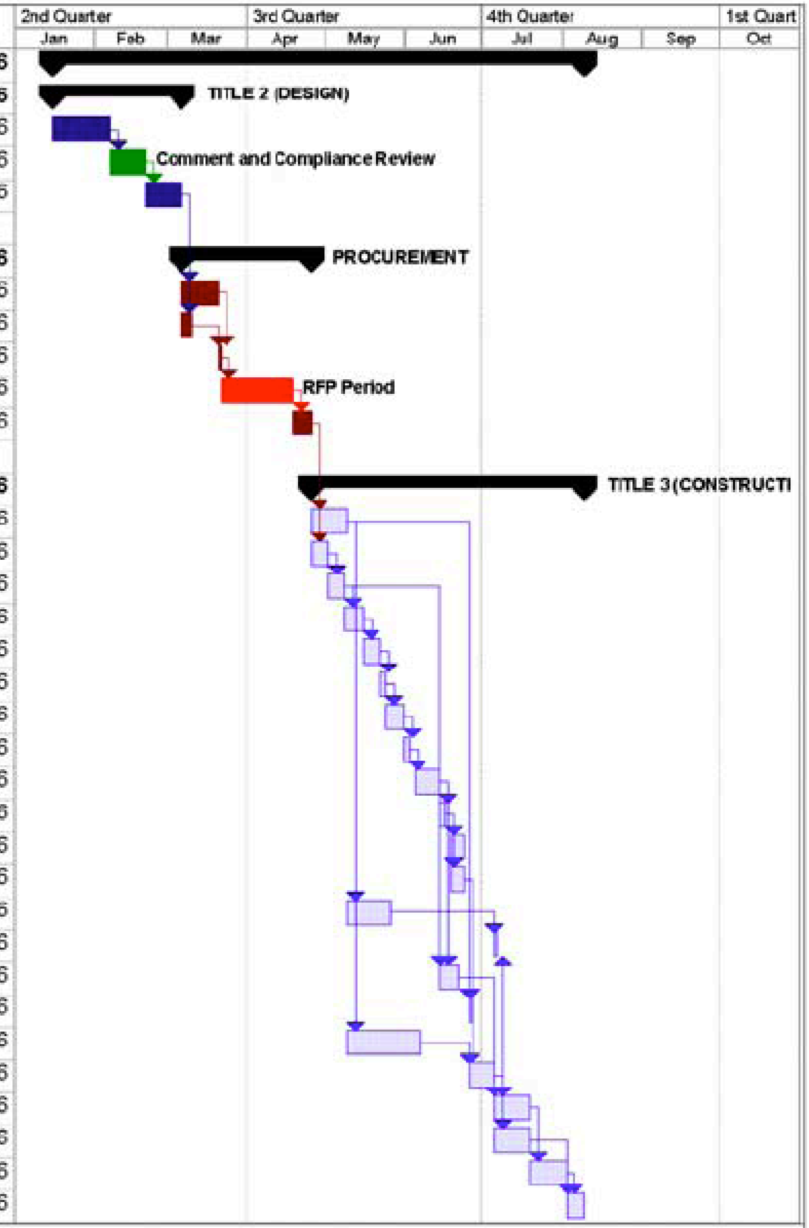
Radiative Delta Decays

•



Schedule

ID		Task Name	Duration	Start	Finish
1		**SCiBAR**	**147 days**	**Mon 1/16/06**	**Wed 8/9/06**
2		**TITLE 2 (DESIGN)**	**35 days**	**Mon 1/16/06**	**Mon 3/6/06**
3		Design	15 days	Mon 1/16/06	Mon 2/6/06
4		Comment and Compliance Review	10 days	Tue 2/7/06	Mon 2/20/06
5		Complete Design	10 days	Tue 2/21/06	Mon 3/6/06
6					
7		**PROCUREMENT**	**36 days**	**Tue 3/7/06**	**Tue 4/25/06**
8		Start Req/Circulate for Signatures	10 days	Tue 3/7/06	Mon 3/20/06
9		Assemble Documents	4 days	Tue 3/7/06	Fri 3/10/06
10		Issue RFP	1 day	Tue 3/21/06	Tue 3/21/06
11		RFP Period	20 days	Wed 3/22/06	Tue 4/18/06
12		Issue NTP	5 days	Wed 4/19/06	Tue 4/25/06
13					
14		**TITLE 3 (CONSTRUCTION)**	**76 days**	**Wed 4/26/06**	**Wed 8/9/06**
15		Shop Drawings	10 days	Wed 4/26/06	Tue 5/9/06
16		Mobilize	5 days	Wed 4/26/06	Tue 5/2/06
17		Excavation	4 days	Wed 5/3/06	Mon 5/8/06
18		Base Slab	5 days	Tue 5/9/06	Mon 5/15/06
19		Lower Wall F/B/P	5 days	Tue 5/16/06	Mon 5/22/06
20		Lower Wall Strip Forms	2 days	Tue 5/23/06	Wed 5/24/06
21		Mid Wall F/B/P	5 days	Thu 5/25/06	Wed 5/31/06
22		Mid Wall Strip Forms	2 days	Thu 6/1/06	Fri 6/2/06
23		Upper Wall F/B/P	8 days	Mon 6/5/06	Wed 6/14/06
24		Upper Wall Strip Forms	2 days	Thu 6/15/06	Fri 6/16/06
25		Underdrains/Backfill	5 days	Mon 6/19/06	Fri 6/23/06
26		Paint Walls	5 days	Mon 6/19/06	Fri 6/23/06
27		Fabricate Roof	13 days	Wed 5/10/06	Fri 5/26/06
28		Install Roof	1 day	Thu 7/6/06	Thu 7/6/06
29		Install Electrical/Comm from MI-12	5 days	Thu 6/15/06	Wed 6/21/06
30		Install Door	1 day	Mon 6/26/06	Mon 6/26/06
31		Fabricate Platforms and Ladders	20 days	Wed 5/10/06	Tue 6/6/06
32		Install Platforms/Ladders	8 days	Mon 6/26/06	Wed 7/5/06
33		Electrical	10 days	Thu 7/6/06	Wed 7/19/06
34		Mechencial	10 days	Thu 7/6/06	Wed 7/19/06
35		Fire Detection	10 days	Thu 7/20/06	Wed 8/2/06
36		Testing/Trim Out	5 days	Thu 8/3/06	Wed 8/9/06



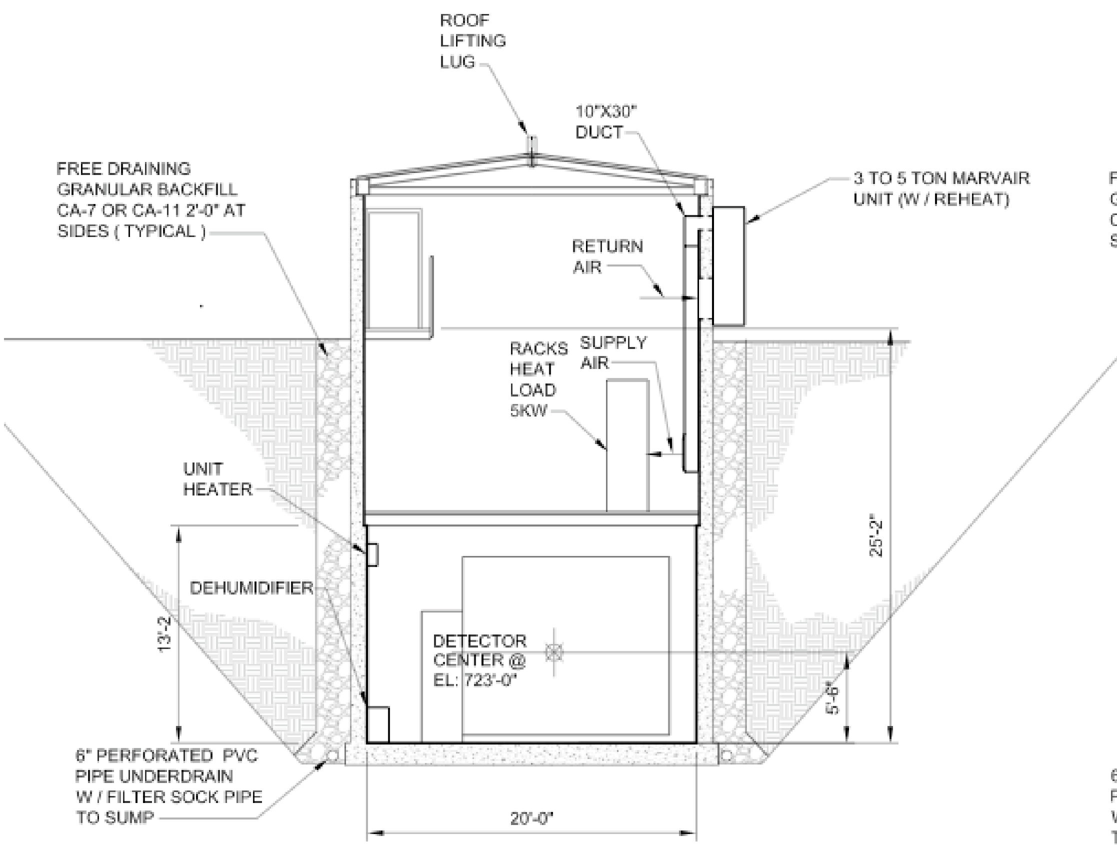
Project Title:	SciBar Enclosure		Project No. 6 7 61	Status: Prel.	Date: 6/9/09	Revision Date: 12/2/09
				Rev.1		
	DESCRIPTION OF WORK:		QUANITY	UNITS	UNIT PRICE	EXTENDED PRICE
01	**SITE CONSTRUCTION**	$131,870				
	Mobolize		1	Lot	$ 5,000.00	$5,000
	Soil Erosion Control		1	Lot	$ 5,000.00	$5,000
	Clear and Grub		0.11	Ac.	$ 5,000.00	$550
	Remove Topsoil		400	CY	$ 12.00	$4,800
	Stone Road & Hardstand		400	cy	$ 18.00	$7,200
	Excavate		3150	CY	$ 12.00	$37,800
	Backfil		3150	CY	$ 16.00	$50,400
	Haul excess materials		2950	CY	$ 4.00	$11,800
	2' Stone Along Wall		144	CY	$ 30.00	$4,320
	Final Seeding and Grading		1	Lot	$ 5,000.00	$5,000
	Concrete	$59,000				
	Mud Slab		3.75	CY	$ 200.00	$750
	Base Slab		20	CY	$ 300.00	$6,000
	Lower wall at 14"		39.5	CY	$ 500.00	$19,750
	Mid Tier Wall at 10"		36	CY	$ 500.00	$18,000
	Above Grade Walls		24	CY	$ 500.00	$12,000
	Increase for A Grade Exposed Forming		1	Lot	$ 2,500.00	$2,500
	Steel	$27,788				
	Floor Framing		1.8	Ton	$ 3,900.00	$7,020
	Grating		352	SF	$ 26.50	$9,328
	Misc Framing		1	Lot	$ 2,000.00	$2,000
	Roof (Hatch) Framing		2.1	Ton	$ 3,900.00	$8,190
	Ladder		25	LF	$ 50.00	$1,250
	Doors and Moisture protec	$9,330				
	3' x 7' Man door		1	Ea.	$ 700.00	$700
	Metal Roofing		390	SF	$ 12.00	$4,680
	Semi Rigid Insul		1150	SF	$ 3.00	$3,450
	Misc Caulk and Sealants		1	Lot	$ 500.00	$500
	Finishes	$14,725				
	Painting Concrete		2350	SF	$ 3.00	$7,050
	Painting Steel		1	Lot	$ 1,800.00	$1,800
	Dampprooffing		2350	SF	$ 2.50	$5,875
	Mechanical & Plumbing	$15,270				
	Sump Pump (Single sewage package syste		1	EA	$ 1,000.00	$1,000
	Install Sump Pump		1	Lot	$ 206.00	$206
	Underdrain Piping		70	LF	$ 9.00	$630
	PVC Discharge		40	LF	$ 20.24	$810
	Dehumidifier		1	EA	$ 3,775.00	$3,775
	Condensate Drain Piping		25	LF	$ 12.77	$319
	Unit Heater 5 KW		1	Ea	$ 550.00	$550
	Duct (30x10at 18')2.7lbs/sf		400	LB	$ 6.70	$2,680
	AC unitfor Racks (basis 5 ton marvair with		1	Ea	$ 5,000.00	$5,000
	Install AC Unit		1	Lot	$ 300.00	$300
	Fire Detection	$18,000				
	Air Sampling Smoke Det.		1	Lot	$ 12,750.00	$12,750
	Fire Alarm Control Panel		1	Ea.	$ 3,500.00	$3,500
	Manual Pull Station		1	Ea.	$ 450.00	$450
	Combination Horn & Strobe		2	Ea.	$ 650.00	$1,300
	Electrical	$42,865				
	Trench Power & Comm from MI-12		350	LF	$ 30.00	$10,500
	3" Rigid from MI-12 Comm. & Firus		350	LF	$ 27.00	$9,450
	3" Rigid from MI-12 Power		350	LF	$ 27.00	$9,450
	Elec Cable		16	CLF	$ 280.00	$4,480
	480V Power Disconects		2	Ea.	$ 795.00	$1,590
	120/208V Panelboard (225 Amp)		1	Ea.	$ 400.00	$1,850
	Transformer		1	Ea.	$ 3,645.00	$3,645
	Utility Outlets		3	Ea.	$ 100.00	$300
	Lights 4' Fluor.		3	Ea.	$ 100.00	$300
	Exit Lights		1	Ea.	$ 100.00	$100
300	Emerg. Lights		2	Ea.	$ 100.00	$200
	Misc Conduit		1	Lot	$ 1,000.00	$1,000

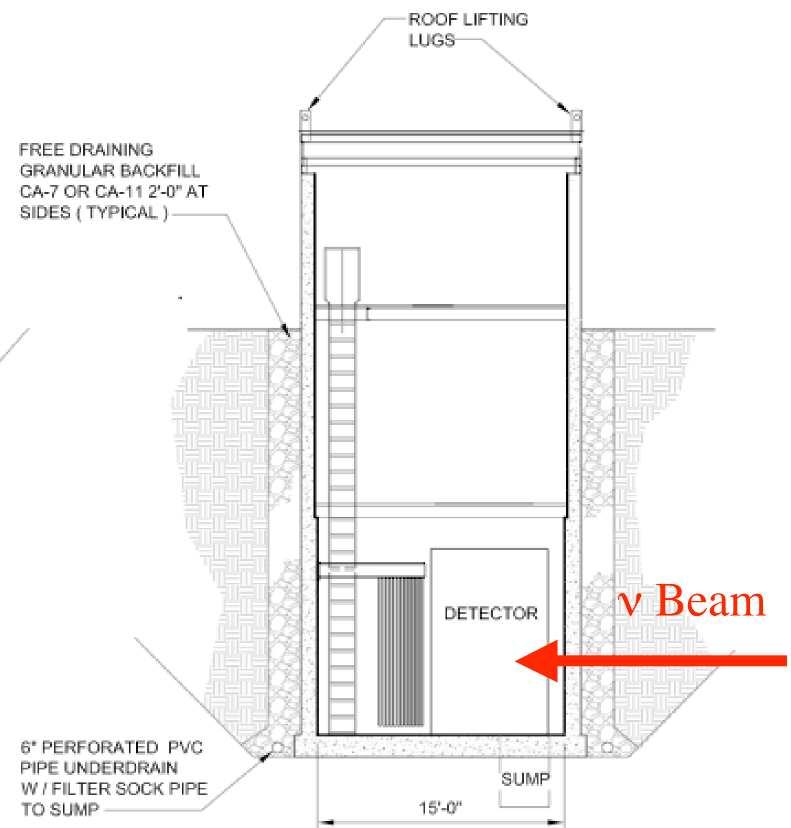
	SciBar Enclosure	Project No. 6 7 61	Status: Prel.	Date: 6/9/09	Revision Date: 12/2/09
			Rev. 1		
	Construction Contract				
	Subtotal				$317,848
	O&P @20 %				$63,570
	Anticipated Contract Price				**$381,417**
	Project Overheads				
	EDIA @21%				$80,098
	Subtotal				$461,515
	Contingency and Management Reserve @20%				$92,303
	Other Overhead (G&A)				$94,757
	Plant Project Total				**$648,576**

Civil Construction Cost Breakdown

Indirect rates	
CSS	18.5%
MSA	5.5%
G&A	10.0%

EDIA		
	In-House	80,098
	A/E	0
Construction		381,417
Mgt. Reserve		92,303
	Subtotal	553,818
Indirect		94,757
Total Project		**$648,576**


ROOF
LIFTING
LUG
10"X30"
DUCT
FREE DRAINING
GRANULAR BACKFILL
CA-7 OR CA-11 2'-0" AT
SIDES (TYPICAL)
3 TO 5 TON MARVAIR
UNIT (W / REHEAT)
RETURN
AIR
RACKS
HEAT
LOAD
5KW
SUPPLY
AIR
UNIT
HEATER
DEHUMIDIFIER
DETECTOR
CENTER @
EL: 723'-0"
13'-2
25'-2"
5'-6"
6" PERFORATED PVC
PIPE UNDERDRAIN
W / FILTER SOCK PIPE
TO SUMP
20'-0"


ROOF LIFTING
LUGS
FREE DRAINING
GRANULAR BACKFILL
CA-7 OR CA-11 2'-0" AT
SIDES (TYPICAL)
DETECTOR
ν Beam
6" PERFORATED PVC
PIPE UNDERDRAIN
W / FILTER SOCK PIPE
TO SUMP
SUMP
15'-0"